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Table of Contents

4 News Notes

by Mr. Dennis Lindell

6 Improving Commercial Aircraft Safety

by Mr. Charles Frankenberger and Mr. William Emmerling

The NAWCWD has been working with the FAA under the ACFPP to transfer vulnerability-assessment computational models to conduct commercial safety analysis to assess aircraft hazards resulting from uncontained engine failures.

10 Airliner Air Force: Survivability for Militarized Commercial Aircraft

by Dr. Torg Anderson and Dr. Lenny Truett

As an attractive, cost-saving measure, the Services are looking more and more at large commercial aircraft to accomplish select missions. While this cost saving may be extremely appealing, there are hidden costs that must be understood. In the area of survivability, you get what you pay for.

12 Improved Fire-Test Criteria for Aircraft Insulation

by Mr. Gus P. Sarkos

The FAA recently adopted new, improved flammability-test standards for thermal-acoustic insulation used in transport airplanes. The new standards will improve aircraft safety. The Fire Safety Branch at the FAA's William J. Hughes Technical Center developed the new insulation-flammability test methods.

16 Excellence in Survivability: Dr. Leonard F. Truett, III

by Mr. Dale Atkinson

JASPO is pleased to recognize Dr. Lenny Truett for Excellence in Survivability. Dr. Truett is a Research Staff Member with the IDA where he provides support to the OSD/DOT&E on aircraft survivability programs.

18 National Aeronautics and Space Administration (NASA) Aircraft Hardening and Airspace Security Research

by Mr. Douglas A. Rohn

NASA's long-range research and development capabilities have provided advances in all areas of aviation; therefore, as noted by NASA Administrator Sean O'Keefe in the NASA 2003 Strategic Plan, "The increasingly complex and dangerous international arena compels us to aggressively apply our expertise and technologies to improve homeland security."

24 The Transportation Security Administration's Commercial Aircraft Hardening Program

by Mr. Howard J. Fleisher

The overriding historical goal of the program has been to protect commercial aircraft from catastrophic structural or critical-system failure caused by a terrorist-initiated event. The program has been focused on determining and identifying the minimum size explosive that would result in aircraft loss, and assesses other intentional threats to aircraft including electromagnetic interference, projected energy, MANPADS, and small-arms fire.

28 CSI: On the Battlefield

by Ms. Melissa Winthrow

Some of today's most popular television shows feature crime scene investigation, but those pale in comparison to the real-life battlefield investigations an Air Force Research Laboratory scientist carries out.

30 Annual Survivability Awards Presented by Combat Survivability Division

by Mr. John Vice

These awards, presented annually at the NDIA Combat Survivability Division's Aircraft Survivability symposium, recognize individuals or teams who demonstrate superior performance across the entire spectrum of survivability, including susceptibility reduction, vulnerability reduction, and related modeling and simulation.

Letters to the Editor

Mr. Ketcham,

I encountered your article, "The Survivability Assessment Subgroup Strategic Plan," in the Fall 2004 Aircraft Survivability. It is unfortunate that your otherwise thoughtful article was tainted with a biased and uninformed discussion of the current vulnerability "architectures" in use in the Department. I take specific issue with your writing beginning in the third column of page 10, "One of the worst examples..." I request that your editors provide equal space to more accurately present the technical issues that got us where we are and that need to be considered for the future.

The reader is not provided enough context to understand what the "frameworks" are and why they were developed. Instead the article exploits the simple fact that there are three (there are actually more) to make the questionable point that there should not be three. It is also a mischaracterization to call them all frameworks. In the software engineering sense of the word only one of them is a framework. The code bases mentioned stem from three different eras of computer science and that is the essence of why they all exist. COVART's origins are in the early work of the late 1960 and early 1970s, and represent one part of the trifurcation of VAREA, which was the original attempt by the Joint community to standardize on a single tool in 1970. COVART probably represents what is right about Joint development but it is brittle and difficult to enhance. It is fundamentally based on 1960s software technology (i.e., subroutine based Fortran code). The AJEM code base has as its foundation the second piece of the trifurcation with its lineage thru SQuASH and now MUVES, principally developed by ARL. Ironically, AJEM grew from the Dahlgren re-visitation of the 1970s vision of "one model for all" and may have grown to represent what was wrong with Joint development (e.g., design by committee). It is fundamentally based on 1980s technology (i.e., object based C code).

The Endgame Framework was not conceived as a "one tool for all"—it is fundamentally a C++ framework for building multiple applications. It

is my belief (widely shared in some circles) that the "one tool for all" concept is fundamentally flawed. While superficially this concept (as your article espouses) appears to be a solution to our resource, accreditation, and other MS&A woes, the pragmatic reality is that across the community we have different needs for our software tools. This reality drove the trifurcation in the 1970s and it still drives the community today (e.g., Aircraft design and vulnerability reduction is a different engineering problem than weapon lethality and effectiveness and different tools are required). Notwithstanding the sometimes differing emphasis in our models there is no doubt the fundamental physics is the same. I believe this truth, incorrectly extended, is at the root of the "one tool for all" fallacy. Algorithms, methodologies and characteristic data need to be agreed upon and standardized. Software tools need to be developed that consider both these aspects AND the intended users (a two-pronged approach as Jim Rumbaugh would say). The "one tool for all" concept presumes that all the users can be satisfied simultaneously. This presumption is both unlikely philosophically and has historically led to failure.

Modern software engineering is clear in its presentation of the value of modularity and while it is no silver bullet it is as close to one as we are likely to get in its object oriented incarnation. This computer science technology offers us a solution to the challenge we keep revisiting (i.e., how best to develop/manage software for V/L applications). I submit what we need to be debating is not what "architecture" we use to build our tools from but what are the fundamental algorithms, methodologies and characteristic data of concern. We can then standardize, verify, validate, and accredit "reference modules" in the form of reports, subroutines, functions or classes (as appropriate) and test cases. The Joint coordinating groups could then manage the configuration of the methodology, their interfaces and reference implementations at the same level of granularity and leverage the conceptual modularity that modern computer science provides. In due course, the Joint groups could then provide these products to anyone with need to know for use in software

customized for their own needs. Whether they use COVART, AJEM, EF or whatever is their business. It should be sufficient that they are using accredited methodology.

The Endgame Framework in its latest version represents the state of the art in engineering (software AND physical) and can provide both a home for any number of standard modules in a way that FACILITATES Joint development and a foundation for building custom software. None of the other architectures you mentioned can make those claims or even come close to doing it. EF is under multi-agency configuration management, is documented and ready to try on for any V/L challenge. The community should try it. If it doesn't provide a better foundation than what they have they don't have to use it. Choice is what our country is based on after all.

Regards,

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Mr. Talbot

I have reviewed your comments and feel they deserve a reply. Let me say first that this E-mail may sound a little terse in tone. However that is more a reflection of my desiring to be direct and brief. It does not reflect any animosity I have towards you, or your E-mail.

I stand by my remarks in the article you quote from the Aircraft Survivability journal. The specific remarks you addressed were obviously subjective in nature and represents my own opinion. I have no horse in this race.

continued on page 17

News Notes

■ by Mr. Dennis Lindell



Mr. Joe Jolley Retires from Civil Service

Mr. Joe Jolley retired from civil service December 3, 2004. Mr. Jolley served as the Army Civilian Representative to the Joint Aircraft Survivability Program Office (JASPO) staff for the prior 14 plus years having joined what was then the JTCG/AS Central Office in February 1990. Mr. Jolley came to the JASPO from the Naval Air Systems Command's Propulsion Division where, for six years, he provided engineering support for the F414 and other engines on Navy and Marine Corps aircraft. Prior to joining NAVAIR, Mr. Jolley served on active duty in the Air Force as an aircraft maintenance officer. He retired from the Air Force Reserve in February 1993 as a Lieutenant Colonel.

Mr. Jolley has been a stalwart in the JTCG/AS Central Office and now the JASPO for many years, providing excellent managerial and technical support which greatly contributed to our goal of establishing survivability as a design discipline and providing more survivable aircraft to the warfighter. During his tenure with the JAS program office, one of his responsibilities was editor of

the Aircraft Survivability Journal where he was instrumental in helping develop the journal into a respectable publication representing the aircraft survivability community and design discipline. For a brief period from August 2001 to January 2003, Mr. Jolley was detailed to serve on the staff of the Commission on the Future of the United States Aerospace Industry. Mr. Jolley served as the JASPO Deputy Program Manager for the last two years.

Mr. Jolley continues to support the JASPO part time as a consultant with Survice Engineering and we look forward to his continuing support.

Aircraft Combat Survivability Short Course

The Joint Aircraft Survivability Program (JASP) and the Survivability Vulnerability Information Analysis Center (SURVIAC) are co-sponsoring a three-day Aircraft Combat Survivability Short Course to be held July 26–28, 2005. The course will be held at Wright-Patterson AFB, Ohio. The course is open to Government and Industry personnel who would like to learn more about the aircraft combat survivability discipline. The course will cover a broad spectrum of topics including—

- Introduction to survivability
- The essentials of aircraft combat survivability
- Modeling and simulations for survivability
- Current technology focus areas for survivability
- Joint Live Fire for aircraft systems
- Support for validation, verification and accreditation of models

There is no course fee. A small charge may be required to cover incidentals. Registration will be limited to 75. For any questions or to obtain a registration form, please contact Mr. Darnell Marbury at 703.607.3509, ext. 10 or by E-mail at darnell.marbury@navy.mil.



Mr. Bob Hood is the new JASP Vulnerability Reduction Subgroup Chairman

Mr. Robert Hood is replacing Mr. Robert Wojciechowski "Wojo" as the Army co-chair and Chairman of the JASP Vulnerability Reduction Subgroup. Mr. Hood has spent most of his career at the Aviation Applied Technology Directorate, involved with numerous aircraft and support systems development, test, and qualification programs. He is currently the team leader for subsystems at AATD and is responsible for a wide range of technologies, primarily in the areas of crashworthiness, fuel systems, and ballistic protection, including ballistic test and qualification for both fuel and protective systems. Mr. Hood has a B.S. in Mechanical Engineering from North Carolina State University and a Masters of Engineering Administration from George Washington University, Washington DC, is a member of the Army Acquisition Corps, and is retired from the U.S. Army Reserve.

Mr. Wojciechowski will continue to support the JASP as his schedule permits. Please join the JASPO in thanking Mr. Wojciechowski for his service and in welcoming Mr. Bob Hood as the new VR Subgroup Chairman.

New Requirement for Survivability

The Fiscal Year 05 National Defense Authorization Act (NDAA) added a new requirement for survivability in Section 141. The requirement reads as follows—

Consideration of Force Protection in Asymmetric Threat Environments.

SEC. 141. Development of Deployable Systems to include:

a. **Requirement for Systems Development**—The Secretary of Defense shall require that the Department of Defense regulations, directives, and guidance governing the acquisition of covered systems be revised to require that—

1. An assessment of warfighter survivability and of system suitability against asymmetric threats shall be performed as part of the development of system requirements for any such system; and

2. Requirements for key performance parameters for force protection and survivability shall be included as part of the documentation of system requirements for any such system.

b. **Covered Systems**—In this section, the term “covered system” means any of the following systems that is expected to be deployed in an asymmetric threat environment:

1. Any manned system.
2. Any equipment intended to enhance personnel survivability.

c. **Inapplicability of Development Requirement to Systems Already Through Development**—The revisions pursuant subsection (a) to Department of Defense regulations, directives, and guidance

shall not apply to a system that entered low-rate initial production before the date of the enactment of this Act.

d. **Deadline for Policy Revisions**—The revisions required by subsection (a) to Department of Defense regulations, directives, and guidance shall be made not later than 120 days after the date of the enactment of this Act.

This adds increased importance to survivability in the acquisition process and the JCS/J8 has already identified survivability as a key performance parameter in their capability requirements process.



New NDIA CSD Chairman

The National Defense Industrial Association's Combat Survivability Division (CSD) has a new Chairman. ADM Bob Gormley, USN (ret) passed the CSD gavel to Maj Gen John W. Hawley, USAF (ret) at the group's annual symposium in Monterey last November. Maj Gen Hawley, who is President and CEO of CollaborX, Inc., has extensive experience in the survivability area having defended the survivability requirements of the F/A-22, B-2, JSF, and JAASM to Congressional Staff Members and others. Maj Gen Hawley was an F-16 pilot, Fighter Wing Commander, and held increasingly responsible positions in the operational and acquisition communities. In his last position he was Commander of the Aerospace Command and Control, Intelligence, Surveillance and Reconnaissance Center at Langley AFB, Virginia, where he created and led the organi-

zation charged with overseeing the development of the Air Force command center information systems and intelligence, reconnaissance and surveillance systems. During 1992–1993, he was the Commander of the Coalition Task Force Provide Comfort in Turkey providing aid and comfort to the Kurds in Iraq. The JASPO Program Manager is a member of the CSD Executive Board and one of the sponsors of the annual survivability symposium. JASPO welcomes Maj Gen Hawley to the survivability community and wishes him the best in his new job.



Mr. Robert Lyons joins JASPO

The JASPO welcomes Mr. Robert Lyons as the newest member of the JASPO staff. Robert has been involved with aircraft survivability for most of his career. While at the Naval Weapons Center, China Lake (now Naval Air Warfare Center Weapons Division), he conducted many ballistic and chemical intrusion tests on the F/A-18 and A-6E aircraft. Robert then moved to the Air Force Flight Test Center, Edwards AFB, California, to lead the survivability flight test effort for the B-2 Spirit bomber. The last few years, he has been working for the Space and Naval Warfare System Center, San Diego, as a project lead for Navy SIGINT programs. Mr. Lyons has a B.S. in general engineering from UCLA. Robert is a welcome addition to the JASPO and will be the Deputy PM for Susceptibility Reduction. ■



Improving Commercial Aircraft Safety

■ by Mr. Charles Frankenberger and Mr. William Emmerling

On December 6, 1995, Pakistan International Airlines (PIA) flight 722, a Boeing 747-240 “Combi” airplane,¹ experienced an uncontained failure² in the Low-Pressure Turbine (LPT) area of the No. 2 engine shortly after takeoff from John F. Kennedy International Airport (JFK), New York.³ The flight crew reported that as the airplane was climbing through 1,000 feet, they heard a loud thud and grinding noise and that the airplane then yawed to the left. The flight engineer reported that immediately after he heard the thud, he noted that the No. 2 engine oil-pressure and oil-quantity gauges both indicated zero. The flight crew continued the climb and later shut down the No. 2 engine. The airplane returned to JFK and landed without further incident. None of the 240 passengers and 15 crew members on board were injured. The airplane was operating on an Instrument Flight Rules (IFR) flight plan under the provisions of Title 14, Code of Federal Regulations (CFR), Part 129, as a regularly scheduled international passenger and cargo flight from JFK to Charles de Gaulle Airport, Paris, France.

The examination of the No. 2 engine revealed that most of the LPT module was missing. The airplane had punctures to its left-wing leading-edge slats and to a landing-gear door. The No. 1 engine also had hard-body impact damage⁴ to 18 of the 38 fan blades, and the fan cowl had impact damage from the debris ejected from the No. 2 engine.

The Survivability Division of Naval Air Warfare Center, Weapons Division (NAWCWD) has been working with

the Federal Aviation Administration (FAA) under the Aircraft Catastrophic Failure Prevention Program (ACFPP) to transfer vulnerability-assessment computational models to conduct commercial safety analysis to assess aircraft hazards resulting from uncontained engine failures. The FAA initiated the ACFPP in response to the United Airlines accident at Sioux City, in which an uncontained engine failure caused the loss of all hydraulics (flight controls) on the DC-10 aircraft, resulting in a crash landing.

The Aircraft Catastrophic Failure Prevention Program, lead by the FAA Technical Center, is sponsored by the FAA’s Transport Airplane Directorate and Engine and Propeller Directorate. China Lake’s involvement in this program began in 1995 as a result of a common interest to better understand the effect of uncontained engine failures on aircraft systems. Uncontained engine failures are high-energy events that result in large and small pieces of rotating engine components penetrating the engine casings and damaging aircraft structure and systems. Under a Joint Live Fire (JLF) test program an operating F404 underwent a ballistic test, which resulted in a catastrophic uncontained engine failure.

An event resulting in the release of uncontained debris from an aircraft engine can have devastating effects on the aircraft and result in the catastrophic loss of an aircraft. FAA, under the ACFPP, has initiated several activities aimed at understanding and mitigating the effect of uncontained engine events. NAWCWD was tasked to characterize the uncontained engine debris, develop an uncontained engine

debris analysis tool, and validate the tools through testing.

The product of this effort is a design process consistent with analysis and methodology tools used in the Aircraft Survivability discipline. These tools will assist aircraft and engine designers in minimizing the vulnerability of turbine-powered aircraft to uncontained engine failure in compliance with FAA regulations.

Debris Characterization

Title 14, CFR 25.903(d)(1), states that “Design precautions must be taken to minimize the hazards to the airplane in the event of an engine rotor failure...” Minimizing the hazard to the airplane can be accomplished in several ways—

1. Minimize the frequency of uncontained disc events;
2. Minimize fragment energies, quantities, and related trajectories; and
3. Mitigate the hazards to safe flight through mitigation provided in aircraft design and construction.



Figure 1. F404 ballistic test, uncontained failure

It is understood that absolute containment for all events is unlikely; thus system separation, minimizing fragment energies, and mitigating in the aircraft are the methods of compliance.

The NAWCWD debris-characterization effort was conducted with the oversight of the engine specialists of the Aviation Rulemaking Advisory Committee (ARAC). Specific recommendations for data analysis and component failure mechanisms from the specialists have been incorporated into the product of this effort.

Work began in FY96 with the collection of data to develop a historical perspective of uncontained engine events. A database was developed that includes details of 73 well-documented events. The data spans the period from November 1961 through the present and was collected through on-scene investigation and the historical records of private-sector engine and airframe companies.

The database provided a means to characterize debris sizes and trajectory angles for specific component failures and to normalize the data for application to a variety of engines. Two groups of debris data were of special interest—

1. Small fragments (blade pieces) that are lower in energy and may be mitigated with appropriate aircraft skin thickness, and
2. Large debris (large blade fragments or disk sections) that may only be mitigated with system redundancy and separation.

The database contains information from narrow- and wide-body commercial transport aircraft including the Boeing 707, 720, 737, 727, 747, 767; the Douglas DC-8, DC-9, MD-80, MD-88, DC-10; the Lockheed L1011; and the Airbus A300. Engines include Pratt and Whitney JT3D, JT4A, JT8D, JT9D, TF33; General Electric CF6; Rolls Royce RB211, and Conway 508.5

The ARAC Power Plant Installation Harmonization Working Group 25.903(d)(1) Task Group has drafted the engine uncontained-fragment

Uncontained Engine Debris Damage Mitigation Program

- **Uncontained Engine Debris Characteristics**
 - Collected uncontained event data (~73 events with detailed damage information)
 - Conducted analysis to define uncontained debris characteristics
 - Size, weight, velocity, trajectory, and quantity of fragments for a given event
- **Rotor Burst Safety Assessment Tool (UEDDAM)**
 - Implemented modifications to vulnerability assessment codes (FASTGEN and COVART) to better model the threat and provide the desired output
- **Validated Tools through Test**
 - Developed new penetration equations for large, slow fragments
 - Validated through panel and fuselage testing



Figure 2. Program objectives

model for the planned revision to Advisory Circular (AC) 20-128A. One product from the NAWCWD effort is a generic fragment model that will characterize the multiple fragments that result from an uncontained engine failure. It is the intent of the FAA that this model be the basis of the update to the AC.

Uncontained Engine-Debris Damage-Assessment Model (UEDDAM)

The second part of the NAWCWD effort was to develop an analysis tool based on the vulnerability-assessment codes used to assess military aircraft to foreign threats. The NAWCWD teamed with SURVICE Engineering Company and KETRON to leverage the existing vulnerability-assessment codes through the development of UEDDAM.

UEDDAM is intended to fill an industry and FAA need for an analytical tool capable of conducting rotor-burst assessment that incorporates fragment penetration, system-level hazard assessment, and multiple-fragments analysis. UEDDAM was developed as a design tool capable of conducting aircraft configuration trade studies and as a certification tool to show compliance with Title 14 CFR 25.903(d)(1). It should be noted that UEDDAM provides one means of compliance; other “in-house” analysis methods also provide acceptable means to show compliance with this regulation.



Figure 3. Fan-Disk and Blade Debris

UEDDAM is a wrap-around code that uses Fast Target Generation Model (FASTGEN) and a modified version of the Computation Calculation of Vulnerable Area and Repair Time (COVART) model. Modifications to COVART include penetration equations more suited to engine disk and blade fragments than the existing penetration equations.

UEDDAM allows an analyst to accurately model an uncontained engine failure through modeling the aircraft geometry, system-level dependencies, and debris (threat) characteristics. A Monte Carlo analysis technique is used to provide an aircraft-hazard probability. Based on debris definition and aircraft geometry, UEDDAM calls FASTGEN to develop debris-fragment trajectories through the aircraft. COVART provides penetration assessment based on these trajectories and debris characterizations and then summarizes the component contribution to the aircraft-hazard level.

Table 1. Uncontained-event statistics

Event Type	Average Number of Damages per Event	Maximum Number of Damages in a Single Event	Minimum Number of Damages in a Single Event
Fan Disk	21.9	73	3
Fan Blade	8.2	32	2
Compressor Disk	8.5	19	1
Compressor Rim	6.3	14	2
Turbine Disk	17.2	81	5
Turbine Rim	10.3	28	3
Turbine Blade	8.8	15	2

The results from COVART are accumulated by UEDDAM for multiple iterations of fragment trajectories from a single-release origin, multiple-release origins about the circumference of the rotor disk, and multiple rotor assemblies (stages in the engine). UEDDAM generates hazard-probability output for each event in summary format and also provides details of the critical component contribution for each iteration of the Monte Carlo analysis. A tabulation of risk angles for each critical component/event is also provided. Debris types may be assessed independently or together as a single evaluation of the hazard for the specified debris uncontained event. This part of the code provides tables required by the FAA as part of the Title14 CFR 25.903 data package.

As a design tool, UEDDAM can provide early insight into rotor-burst hazard for an aircraft configuration. As a certification tool, UEDDAM provides a standardized approach to conduct rotor-burst hazard assessment.

UEDDAM output provides insight into the rotor-burst hazard in several ways. UEDDAM output can be used to develop a top-level, one-in-20 analysis to address compliance to CFRs. It also provides specific details at the system and component level. The output can be categorized by rotor or debris category, providing a high level of flexibility in viewing analysis results. Through the use of UEDDAM as a design tool, a history of trade-study results can be used to support the minimization intent of the rule.

It is well understood that a rotor burst analysis is a complex analysis. UEDDAM was developed to provide useful tools to aide in conducting the analysis and presenting the results. A UEDDAM Visualizer was developed, which provides visualization of the complex data and information generated from a UEDDAM run. It permits visualization of aircraft geometry, debris-hazard zones, debris trajectories, probability plots of hazard levels, and translational risk angles.

Validation

The third part the NAWCWD effort involved testing in support of the UEDDAM code; specifically, validating/developing the penetration equations to model the impacts of engine uncontained debris (blades and disk fragments) with aircraft structure. Four series of tests have been completed to date.

The first test series investigated small (less than 2-in square, 0.2 lb) to medium-sized (3-in x 5-in, 0.4 lb) blade fragments impacted into aluminum plates and engine cowlings. Performed in 1998, this early testing also investigated the prediction accuracy of several ballistic-impact prediction methods, accepting both the Joint Technical Coordinating Group for Munitions Effectiveness (JTTCG/ME) Residual Velocity (V_r) and Ballistic Limit (V_{50}) equations as reasonable prediction tools for fan-blade impacts.

A second effort, the following year, investigated small-to-medium-sized fragments impacted into an actual narrow-body commercial aircraft

fuselage. During this series, small (0.3 lb) to medium (0.7 lb) fragments were shot into a 727 commercial aircraft fuselage section at varied locations. Most of these impacts involved the fuselage skin only. Test results showed that the penetration model had excellent agreement with the experimental data for the skin category of shots.

The third test series was a follow-on to the fuselage test and evaluated complex structure (skin, stringer, and frame combinations) impacts with medium 3-in x 7-in, 0.7 lb blade fragments, large 8-in x 8-in, 1.8 lb blade fragments, and larger 3.0 lb disk fragments. Analysis of the test data revealed that the interaction of various aircraft structural elements created some disparity in the ability of the JTTCG/ME penetration equations to make accurate predictions. Analysis of this phenomena determined that the Ballistic Limit (V_{50}) equation developed from the FAA Energy Equation was a more effective prediction tool for both single-skin and complex structural impacts.



Figure 4. UEDDAM high-bypass engine geometric model

All three test series had principally impacted 2024-T3 aluminum. A degree of confidence in predicting the effect of fragment impacts into aircraft skins and complex structures had been attained, in addition to an effective test procedure and analysis methodology.

The fourth test investigated composite materials and metals for use in component shielding applications. Previous testing had focused on aircraft skins and structural components. Airframe companies were interested in materials capable of providing shielding for critical components. Materials tested in this series were selected to support aircraft-design trade studies. Four materials were investigated: 2024-T351 aluminum, Ti-6AL-4V titanium, Inconel® 625 LCF, and a generalized composite. Impact data was used to characterize material ballistic response.

History has shown that commercial aircraft are inherently quite tolerant of uncontained failures because of the redundancy built into the aircraft. Most events result in only minor aircraft damage without

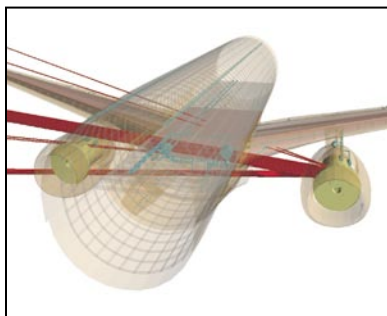


Figure 5. Generic twin UEDDAM model with debris trajectories



Figure 6. A 727 fuselage section arrives at China Lake in support of the Uncontained Engine-Debris Hazard-Mitigation Program.

effecting flight safety. The use of better analysis tools will enhance that inherent capability, thereby producing safer aircraft in the future. ■

Mr. Charles Frankenberger has worked in the propulsion field at NAWCWPNS for 12 years, including eight years in missile propulsion on programs including Tomahawk, Harpoon/SLAM and Advance Air-to-Air Missile. He has worked in Engine Vulnerability issues for the past four-years conducting ballistic tests on turbine engines under JTCG/IAS and LFT efforts. He may be reached at 703.939.8411.

Mr. William Emmerling, PE is the FAA Research Manager for the Aircraft Catastrophic Failure Prevention Program. He has 24 years of design and test experience in propulsion and power drive systems. As manager of the FAA's ACFPP, he also performs research to develop improved LS-DYNA explicit finite element material models for both fuselage protection and engine containment. For fuselage protection, it is envisioned that UEDDAM's vulnerability assessment will identify shielding requirements for specific aircraft locations, and then LS-DYNA can be used for local detailed design of the protection system and attachments as required. Reports from FAA research can be obtained from http://research.faa.gov/aar/tech_reports.asp. Mr Emmerling may be reached by E-mail at william.emmerling@faa.gov.

Notes

1. A Boeing 747 Combi airplane is configured such that it can carry both passengers and cargo on the main deck.
2. An uncontained engine failure occurs when an internal part of the engine fails and is ejected, or results in other parts being ejected, through the cowl.
3. For more detailed information, see Brief of Incident YC961A036.
4. Hard-body impact damage is characterized by a serrated appearance and deep cuts to the airfoil's leading and trailing edges. Hard-body impact damage can result from impact with metal parts, concrete, asphalt, and rocks.
5. The reader is reminded that the inclusion of an engine type does not imply that this engine type is any more susceptible to an uncontained failure than any other engine but that data from such event was available and complete for the purpose of this study. Likewise, the exclusion of an engine type does not imply that the engine type has not had an uncontained failure or is less likely to fail.

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Airliner Air Force: Survivability for Militarized Commercial Aircraft

■ by Dr. Torg Anderson and Dr. Lenny Truett

As an attractive, cost-saving measure, the Services are looking more and more at large commercial aircraft to accomplish select missions. While this may avoid the high development costs of a new platform, the savings go beyond the purchase price, since tried-and-true commercial airplanes have demonstrated low operating costs and high reliability. To further support this argument, the manufacturer and airline logistics systems can be adopted to reduce operational costs. While this cost saving may be extremely appealing, there are hidden costs that must be understood. In the area of survivability, you get what you pay for.

There are numerous recent examples—

- The infamous KC-767 Air Force tanker is no longer in the plan, but it wasn't even going to be purchased by the Air Force—it was a lease arrangement.
- The Air Force is proceeding with the Multi-Mission Command and Control Aircraft (MC2A), or E-10A platform, to replace a number of current aircraft that provide Intelligence, Surveillance, and Reconnaissance (ISR) capabilities and will be fully interoperable with other aircraft and systems. The E-10A will use an extended-range version of the Boeing 767, adding electronics and sensors to accomplish its mission.
- The Army leads the Aerial Common Sensor (ACS) program using a modified Lockheed-Martin Embraer ERJ-145 regional jet with electronic sensors to monitor enemy electronic emissions. This is intended

to replace the Army's RC-12 Guardrail and the Navy's EP-3E ARIES II aircraft.

- The Navy has selected a variation of the Boeing 737 as the platform for its Multi-Mission Maritime Aircraft (MMA) to replace the aging P-3 Orions for anti-submarine warfare. This system is expected to be extremely versatile and capable of conducting a wide range of other combat and non-combat missions.

Since commercial aircraft weren't designed to operate in a combat environment, survivability wasn't considered in their designs. Safety is a major requirement for the airlines, but this is only a starting point for combat vulnerability requirements. For some systems, such as the MMA, confrontations with enemy threats are expected during combat missions. For others like the E-10A, the Services indicate that the system operate clear of the threats and be shielded by suitable support aircraft.

However, if these aircraft accomplish their missions effectively, they will be central features of the U.S. battle force and, as such, will be high value targets for enemies with resourcefulness and capabilities to reach them.

Common Issues

The ability to add vulnerability reduction to a commercial platform varies as much with each program as it does with the platforms. One thing is certain though—it's more difficult to include these features in existing commercial designs for numerous reasons—

- The whole reason for purchasing a commercial system is the

attractive low cost. Expensive changes in design are contrary to this initial philosophy.

- Since the design is virtually complete when the Service program begins, the manufacturer and the program resist any significant design changes. This simply adds time and cost.
- The pre-existing aircraft design puts vulnerability analyses and vulnerability reduction further behind the schedule than usual. It's hard to sell extensive test requirements that would further delay the program.
- To exacerbate the problem, manufacturers are reluctant to release design details because of intellectual property concerns. This also interferes with the vulnerability reduction effort, putting it further behind.

Whether designed for commercial or military use, though, aircraft have some common vulnerability issues when considered for combat. Most of these are obvious. The aircraft structure is directly vulnerable to ballistic impacts. The flight controls are also directly vulnerable or may be incapable of compensating for structural or aerodynamic damage from a combat threat. Fuel tanks introduce vulnerabilities related to hydrodynamic ram structural damage or fires generated in the air space within the tanks. Dry bays provide opportunities for sustained fire when combustibles are ignited directly by ballistic threats or by other ignition sources through cascade damage mechanisms. Just as these are common issues,

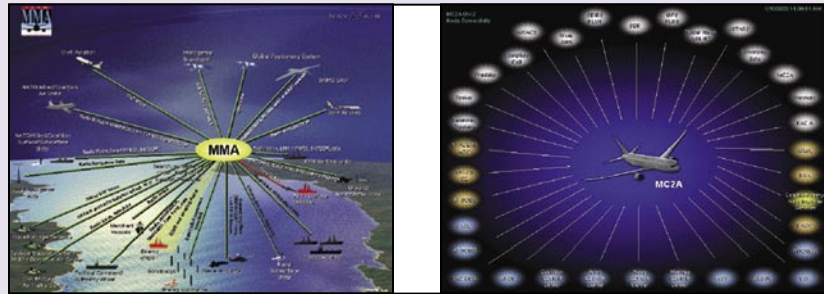
common solutions can be brought to bear

Low-Hanging Fruit

Redundancy and separation of systems are obvious vulnerability reduction methods that can be applied to commercial aircraft if the basic design is not extensively affected. Redundancy in flight controls, hydraulic systems and structural members can significantly reduce vulnerability by preventing single ballistic encounters from affecting critical functions. These considerations come with cost, weight and reliability penalties, though. For commercial applications, component and system reliabilities may be such that redundancy isn't necessary. In military applications, the penalties may still be significant, but the advantages to vulnerability reduction are worth evaluating.

Two vulnerability reduction technologies developed for combat aircraft over the last couple of decades offer significant improvements for survivability in many platforms. Fuel tank ullage inerting replaces combustible air with nitrogen in the fuel tank air space so that an ignition source is not sufficient to start a fire or create an explosion. The C-5 Galaxy employs an inerting system using liquid nitrogen. Commercially available on-board inert gas generating systems (OBIGGS) are capable of separating nitrogen from the air for this purpose. The weight and volume of these systems is significant, but may be acceptable on larger platforms such as commercial aircraft. Survivability analyses and the appropriate trade studies can evaluate the effectiveness of this capability.

Dry Bay Fire Suppression (DBFS) systems have also demonstrated their effectiveness in live-fire tests. These consist of fire detectors, control systems and suppressors that discharge agents in response to fire indications. These agents interfere with the combustion chain reactions and extinguish the fires. Since dry bay fires are a significant contribution to the potential vulnerability of an aircraft, DBFS systems can greatly improve survivability. These components are compact and can easily be accommodated in commercial aircraft designs



It's hard to imagine that the aircraft symbolized at the center of these networks wouldn't be high value targets if they were effective in accomplishing their missions.

with little penalty, but there is a significant design and test effort required to ensure their effectiveness.

Unique Issues

Another advantage of commercial aircraft designs is their extensive operational history that can be used to identify possible design issues. Maybe more importantly, accident and incident histories provide insight into the differences in commercial and military design philosophies that affect vulnerability. Some specific examples can illustrate this—

- Cargo doors on two DC-10's were improperly latched on the ground and were blown off the aircraft as they climbed above 10,000 feet. The resulting explosive decompression created a pressure differential that buckled the cabin floor, causing interference with the flight controls. In one case, control of the aircraft was lost and it crashed with the loss of 346 passengers and crew. Corrective action was repair of the cargo door to prevent improper latching.
- Loss of hydraulic power and resulting loss of all aircraft controls resulted when the fan disk on the #2 engine of a DC-10 disintegrated and ruptured hydraulic lines in the tail of the airplane. A landing was attempted using differential engine control, but the aircraft crashed. One-hundred eleven out of 296 people on board were killed.
- An ullage explosion in the center wing fuel tank of a Boeing 747 resulted from an electrical

short outside of the tank that created an electrical arc in the ullage space (postulated cause, but never proven). The aircraft disintegrated killing 212 people.

- Loss of rudder control and a hard-over rudder resulted in loss of control of 737's in three instances. In one case, control of the aircraft was regained. In the others, the aircraft crashed killing 157 people. The likely cause was associated with the single hydraulic rudder control actuator, although the specifics were never determined.

Perhaps the most apparent difference between commercial and military aircraft design is in the philosophy used to address potential cascade failures. The DC-10 cargo door cases demonstrate this most vividly. In these examples, safety depends on preventing the initiating event to disrupt the cascade chain. The corrective action was to fix the cargo door design and eliminate the possibility of that event. The potential for the remaining cascade remained, but presented no problems in subsequent operations. Similarly, there would have been no problem in the DC-10 hydraulic failure and the 747 ullage explosion events without the initiating event.

When designing for vulnerability reduction, though, the initial event is a ballistic encounter and is given (thus, Pk/h is the probability of a kill given a hit). Survivability must depend on design features that break or eliminate the subsequent cascade chains.

As mentioned earlier, redundancy and separation of systems are also

continued on page 29



Improved Fire-Test Criteria for Aircraft Insulation

■ by Mr. Constantine P. (Gus) Sarkos

The Federal Aviation Administration (FAA) recently adopted new, improved flammability-test standards for thermal-acoustic insulation used in transport airplanes.¹ The standards include new flammability tests for in-flight fire-ignition resistance and post-crash fire burn-through resistance. The new standards will improve aircraft safety “by reducing the incidence and severity of cabin fires, particularly those in inaccessible areas where thermal-acoustic insulation is installed and providing additional time for evacuation by delaying the entry of post-crash fires into the cabin.”¹ The Fire Safety Branch at the FAA’s William J. Hughes Technical Center developed the new insulation-flammability test methods. Information about research and testing completed or under way by the Fire Safety Branch to improve aircraft fire safety can be found at <http://www.fire.tc.faa.gov>.

Introduction

Aircraft thermal-acoustic insulation typically consists of lightweight fiberglass encased in a thin-film bagging material. Practically the entire fuselage is layered with insulation blankets to deaden noise and insulate against heat or cold. Also, heating and air-conditioning ducts may be covered with insulation blankets. The thin-film bagging material holds the fiberglass together and prevents moisture accumulation. Before developing the improved criteria, the FAA flammability test requirements for thermal-acoustic insulation, as prescribed in Title 14 Code of Federal Regulations 25.853, consisted of a vertical Bunsen-burner test method.²

Insulation blankets may be a factor in preventing in-flight fires or in mitigating post-crash fires. In the past, fatal in-flight fires—although relatively rare events—have originated in hidden or inaccessible areas of the aircraft. The preponderance of insulation makes it a likely target for an in-flight ignition source and/or a path for flame propagation and fire growth. Concern over the fire performance of thermal-acoustic insulation was raised by a series of incidents beginning in the mid-1990s. In spite of the Bunsen-burner self-extinguishing requirements, the incidents exhibited surprising flame spread along the bagging material. In all cases, the ignition source was relatively modest and, in most cases, was electrical in origin; *e.g.*, short circuit, arcing caused by chafed wire, or ruptured ballast case. Concern with the flammability of insulation was also raised during the investigation of the fatal Swiss Air MD-11 in-flight fire accident that occurred on September 2, 1998.

Investigators determined that the fire was confined to the space above the cockpit and forward-cabin ceiling and involved the insulation blankets (see Figure 1 below). The Transportation Safety Board of Canada—the Canadian accident investigation agency—recommended that flammability standards for interior materials should be based on realistic ignition scenarios and should prohibit the use of materials that sustain or propagate a fire.

Following the initial incidents involving insulation fires, the FAA sponsored round-robin tests employing the FAA-required Bunsen-burner test method and an industry standard known as the cotton-swab test.³ It became clear that a new fire-test standard was needed after both test methods exhibited certain deficiencies. For example, the Bunsen-burner test produced variable results for some materials, and the cotton-swab test did not adequately discriminate between good and bad materials.



Figure 1. Swiss air MD-11 in-flight fire accident

During a post-crash fire involving an intact fuselage, the time required for an external-fuel fire to penetrate into the cabin, commonly called fuselage burn-through, can be a major factor affecting passenger survival. An analysis of past accidents revealed that burn-through was a factor in occupant survivability in at least 17 accidents from 1966–1993.⁴ The Air Tours B-737 accident in Manchester, England, on August 22, 1985, may be the best example of an accident in which fuselage burn-through was a critical factor impacting occupant survival (see Figure 2 below). Accident investigators estimated that the fuel fire penetrated into the passenger cabin in approximately one minute. Extending the time of fuselage burn-through improves survivability by providing additional time for passengers to escape.

Previous FAA research had focused on thermal-acoustic insulation as being the most practical and cost-effective approach for creating a barrier against fuselage burn-through. No burn-through test standards existed for the insulation. However, dozens of full-scale fire tests demonstrated that materials were available to provide burn-through protection when employed as a replacement for the current fiberglass insulation or when used as a fire barrier with the existing insulation.⁵ It was shown that some materials prevented burn-through for five minutes and beyond, compared to only slightly over two minutes of protection from the current fiberglass insulation and aluminum skin.

In-Fight Fire Resistance

To guide the development of an improved fire-test method, a series of large-scale fire tests were initially conducted in a mock-up of the attic area above the cabin ceiling. This had been the location of the fire in the fatal Swiss Air accident and in several other serious incidents. Moreover, previous testing had shown that some insulation films could ignite and propagate a flame in a confined space. A relatively severe ignition source was used, consisting of a heptane-drenched block of urethane foam.⁶

The results showed the fire performance of the insulation films depend-



Figure 2. Air tours B-737 post-crash fire accident

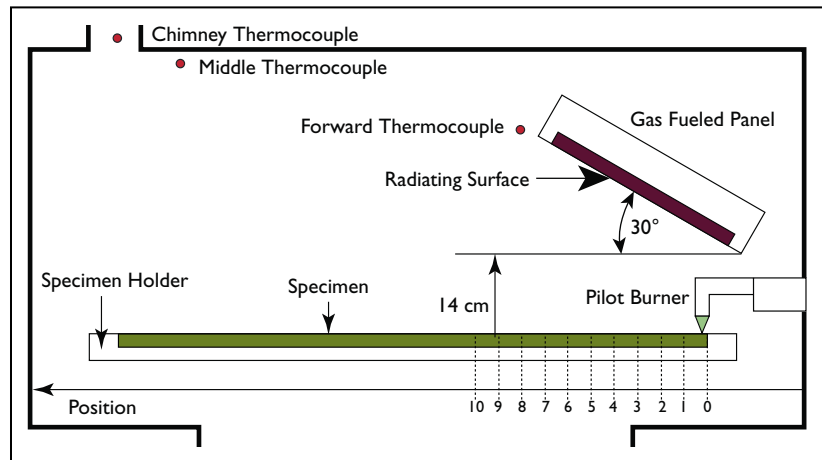


Figure 3. Radiant-panel fire-test apparatus

ed on their chemical composition, weight, and type of scrim (reinforcing) material. Generally, the Mylar® films were relatively flammable, especially the metallized type. Conversely, the Kapton® films exhibited the greatest fire resistance. The Tedlar® films tested at point approximately in between.⁶ From these tests, it became apparent that any new fire-test criteria should prohibit the use of materials that ignite and propagate a fire.

The new test method for in-flight fire resistance is called the radiant-panel fire test since it subjects a material heated by a radiant panel to a pilot flame (see Figure 3 above). It gave a good correlation with the large-scale fire-test data. Pass/fail criteria essentially require that any flaming not extend beyond a two-inch length from the point of flame application or continue flaming after removal

of the pilot flame. Most insulation-cover materials that are currently in use will not meet the new fire-test criteria. For example, based on past tests, most Mylar films, particularly the metallized types, fail the test, as do many of the Tedlar films. Kapton films were good performers, as was one metallized Tedlar film, and would be compliant with the new criteria. However, as previously mentioned, other factors affect the flammability of the insulation-film materials, including weight or thickness, scrim (reinforcing lattice) type and pitch, scrim adhesive, and the use of flame retardants. Now that the rule has been adopted, new film formulations are being developed.

Post-Crash Fire Burn-Through Resistance

The test method for post-crash fire burn-through resistance is a new

performance requirement since it was not explicitly addressed in previous FAA regulations. It is comprised of two main components: a large burner that simulates a jet-fuel fire and a sample holder representative of the fuselage structural framing (see Figure 4 below). The burner flame conditions were set so that the melting time of aluminum sheeting would coincide with full-scale test results. By analyzing past accidents, the required pass/fail criteria for the insulation specimen was set at four minutes because there would be very limited benefit beyond this period; *i.e.*, approximately five minutes, factoring in the skin-melting time. The burn-through time is based on visual observation and measured heat flux through the specimen back face. The FAA has tested numerous samples submitted by industry, and many have passed the required criteria. Compliant specimens fall into three broad cat-

egories: advanced fibrous material (fiberglass replacement), fire barrier with existing fiberglass, and hardened-film material.

Regulatory Activities

Three years before the final rule was issued on thermal-acoustic insulation flammability, on May 26, 2000, the FAA adopted two Airworthiness Directives (ADs)

requiring the replacement of metallized Mylar film used in insulation blankets on over 700 aircraft registered by the U.S.^{7,8} The ADs were prompted by the following—

1. Ground and in-flight fire incidents in aircraft manufactured with insulation blankets covered with metallized Mylar film and
2. Subsequent FAA tests examining the susceptibility to ignition of the types of insulation-cover films used in commercial aircraft

by an electric arc or other small ignition sources.

During the electric-arc ignition tests, the metallized Mylar film was the only insulation film that consistently ignited with significant flame spread. Conversely, the other film materials either did not ignite (Kapton and metallized Tedlar films) or ignited temporarily but self-extinguished with minimal flame spread (plain Mylar film).⁹ Replacement cover materials must be compliant with the aforementioned radiant-panel fire-test criteria.

The new fire-test criteria will impact the type of thermal-acoustic insulation blankets installed in large civil-transport airplanes manufactured after September 2, 2005.¹ On that date, the insulation blankets in newly manufactured aircraft must be compliant with the radiant-panel fire-test criteria, as well as any replacement insulation blankets installed in in-service airplanes. The burn-through fire-test criteria will become effective in newly manufactured aircraft on September 2, 2007. Insulation blankets installed in the lower half of the fuselage must be compliant with the burn-through fire-test criteria since past full-scale fire tests showed that burn-through vulnerability was confined to this area.¹⁰

Current Activities

Work is near completion for planned advisory circulars to support implementing the new flammability requirements for thermal-acoustic insulation. A standardized radiant-panel fire-test methodology is being finalized for evaluating tape and hook and loop (Velcro), which are used extensively in installing and repairing insulation blankets. It has been found that both components can contribute significantly to insulation-blanket flammability. In addition, the method of installing the insulation blankets onto the fuselage framing has a critical effect on the degree of burn-through resistance. By overlapping the insulation blankets and using the proper fasteners, the full potential of burn-through protection can be achieved. For example, factors affecting the effec-

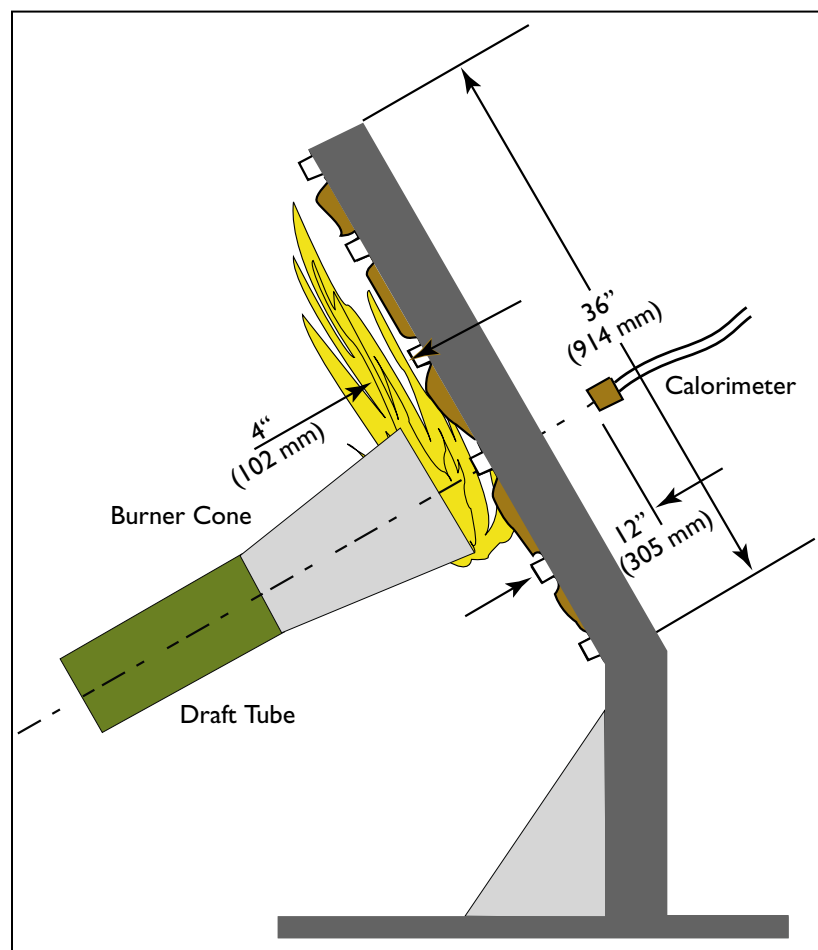


Figure 4. Burn-through fire-test apparatus

tiveness of fasteners (fixing methods) include composition (metal or plastic), through-insulation pins *vs.* clamps, the pitch or spacing of fasteners, and the proper attachment to a stringer or former.

The development of an advisory circular for evaluating tape and hook and loop in the radiant-panel fire test and another for installing insulation blankets that are resistant to burn-through involves the International Aircraft Material Fire Tests Working Group. Comprised of representatives from the aviation regulatory authorities and industry, the Working Group meets regularly to improve existing or develop new fire tests for aircraft materials. In addition to the advisory circulars, round-robin tests are being conducted to improve the repeatability (within laboratory) and reproducibility (between laboratories) of the radiant-panel and burn-through fire-test methods. The status of the Working Group's activities on the new and improved insulation fire tests can be found on the Fire Safety Branch Web site, <http://www.fire.tc.faa.gov> (click on "Materials") The goal of the latter work is to help guarantee that the higher level of safety provided by the more stringent insulation-fire test requirements will be consistently applied by all test laboratories. ■

Mr. Constantine P. (Gus) Sarkos manages the Fire Safety Branch at the Federal Aviation Administration (FAA) William J. Hughes Technical Center. The Fire Safety Branch conducts the FAA's Aircraft Fire Safety Research & Development Program and operates the most extensive civil-aircraft fire-test facilities in the world. Nearly every fire-safety improvement incorporated into commercial airliners worldwide over the past 20 years is a product of this program. Mr. Sarkos is the author of over 50 papers and reports related to aircraft fire safety. He may be reached by E-mail at constantine.sarkos@faa.gov.

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Dr. Leonard F. Truett, III

Excellence in Survivability

■ by Mr. Dale Atkinson

The Joint Aircraft Survivability Program Office (JASPO) is pleased to recognize Dr. Lenny Truett for Excellence in Survivability. Dr. Truett is a Research Staff Member with the Institute for Defense Analyses (IDA) where he provides support to the Director, Operational Test and Evaluation, Office of the Secretary of Defense (OSD/DOT&E) on aircraft survivability programs.

Dr. Truett earned his BS and MS degrees in Aerospace Engineering from the Georgia Institute of Technology in 1991 and 1992, respectively, and then took a job as survivability Research and Development (R&D) Program Manager in the Aerospace Survivability at Wright-Patterson Air Force Base, Dayton, Ohio. He served as a team member on the Halon Replacement for Aviation Program where he was responsible for generating the requirements for an engine nacelle core simulator for the Air Force Engine Nacelle Test Facility and collaborating with the National Institute of Standards and Technology (NIST) in performing experiments to test the effectiveness of numerous potential halon alternatives. The results were published in the journal *Combustion and Flame*, which is the authoritative reference for these types of data. He also won an In-house Laboratory Innovative Research (ILIR) award for developing innovative gas-sampling and analysis techniques.

He returned to school to earn his Ph.D. in Aerospace Engineering from the University of California at San Diego in 2001. His dissertation was on "Experimental Studies of Inhibited Counterflow Flames." He also developed and taught courses on differential equations and mathematical modeling at the Christian Heritage College in El Cajon, California, during this time.

Dr. Truett then returned to Wright-Patterson where he became involved with several important programs. He assisted in developing the Airborne Laser (ABL) Survivability program and served as technical expert and Deputy Program Manager for the C-5 Live Fire Test and Evaluation (LFT&E) program. He was responsible for developing methodology to assess the effectiveness of the ullage inerting system in all fuel tanks and the fire safety system in the wing leading edge and dry bays. Dr. Truett helped develop the portable instrumentation system to monitor oxygen concentration at twenty-four locations during the test, which included the capability to remotely calibrate and control the system. He also served as a technical expert for the Army Halon Replacement Program for Rotorcraft, which was conducted at Wright-Patterson.

Dr. Truett also directed programs for JASPO, formerly called the Joint Technical Coordinating Group on Aircraft Survivability, including a program on the use of aerogels to provide fire protection and infrared (IR) signature reduction called the "Aerogels for Retrofitted Increases in Aircraft Survivability (ARIAS) Program." Dr. Truett co-authored an excellent article on this program for the JASPO Aircraft Survivability Journal in 2002.

In 2003, Dr. Truett took a position with IDA where he is responsible for providing support to DOT&E's Deputy Director for LFT&E on survivability programs for the ABL, C-5, C-17, C-130, and the Army's Future Cargo Aircraft (FCA). He also provides support in the area of fire vulnerability for all aircraft in the LFT&E Program. In this capacity, he conducted an evaluation of the fire vulnerability of the F/A-22 and is assisting in preparing the DOT&E LFT&E report to Congress.

Dr. Truett has published numerous publications in the fire-science area and has received a number of awards for his work, including the Perkins Award for In-house Engineering in 1994 and two Air Force Scientific Achievement Awards in 1998 and 1999.

Lenny's second job generally requires more horsepower than brainpower. He and his wife, Jennifer, own and operate a horse farm in beautiful southern Maryland where they raise and train Warmblood Dressage horses. Jennifer is an avid dressage competitor and keeps Lenny constantly busy with requests for new inventions to make the farm run more smoothly. Caring for horses, goats, dogs, cats, and fish is a lot of work, but he says that having a tractor makes it all worthwhile. Once the farm work is finished, Lenny and Jennifer also enjoy quite moments flying electric radio-controlled airplanes over the treetops.

It is with great pleasure that the JASPO honors Dr. Lenny Truett for his Excellence in Survivability contributions to the survivability discipline and the warfighter. ■

Mr. Dale Atkinson is a consultant on the aircraft combat survivability area. He retired from the Office of Secretary of Defense in 1992 after 34 years of government service and remains active in the survivability community. Mr. Atkinson played a major role in establishing survivability as a design discipline and was a charter member of the tri-service JASPO. He was also one of the founders of the DoD sponsored SURVIAC. He may be reached at jasnewsletter@jcs.mil.

Letters to the Editor con't...

My group does not develop or manage any of the tools listed (COVART, AJEM, or Endgame Framework). The Survivability Assessment Branch I head currently uses COVART. We have evaluated AJEM for use a couple of years ago and may do so again, once it is more robust and stable. We are interested in any tool that adds capability and credibility in the vulnerability/ lethality/ endgame arenas. Furthermore, at no place in the article do I state any preference or make any statement as to which of the tools are technically superior. Therefore, I fail to appreciate the basis for your characterization of my statement as biased. On the other hand, your role as chief proponent of the Endgame Framework is *prima facie* evidence of your self-interest.

I further reject your characterization of my comments in the Aircraft Survivability Journal as being uninformed. To demonstrate this point, it is important to clarify what I said exactly. I was making the point that there is a spectrum of approaches to manage M&S. On one extreme end of the spectrum was mandating direction from a single central authority. The other extreme was a total *laissez-faire* approach with no coordination or direction. I used the current situation with COVART, AJEM and Endgame Framework as an example of this latter extreme. My point was that these three methodologies were an example of a development environment, which currently has little, or no, central guidance or direction. These three applications are being developed and maintained independently of one another with various levels of attempting to address the requirements of the broad user community. In my opinion, your program has the least user involvement outside of your organization. Following is the informed basis for that opinion.

The first I had heard of the Endgame Framework was the 2003 JMUM conference in Monterey. I believe you and a contractor were the presenters. This was the first time many in the audience, including many senior vulnerability engineers and analysts, were made aware of this project. It was particularly bothersome at that point because the Joint Survivability

Community (as represented by the JTCCG/ME and JCTG/AS) had been funding the development of AJEM for several years. This was supposed to be the M&S tool to bring the joint community together.

The next time I heard of your project was at the 2004 JMUM in Colorado Springs. Ron Thompson held an evening vulnerability and lethality working group meeting. Representatives of all three methodologies attended this meeting. I also attended. At that meeting you gave a very informative and interesting brief where you discussed the history of vulnerability M&S. In this brief you also stated that you had a framework that was in search of models and asked the other two groups to supply your program with modules from their respective M&S. This sounded like one of the many appeals from Bob Meyer during the last years of JMASS development. Paraphrasing Bob—"Hey everybody, we built this cool architecture. If you populate it with models you will find it very useful." My point is that to be successful, you probably needed this buy-in much sooner.

In retrospect, I did make one bad choice of words at one point in the article. I would have been better served using the term "methodologies" instead of frameworks. I was not using the computer science form of the word, but the generic common usage (*i.e.*, a set of assumptions, concepts, processes, and practices). Nevertheless, methodologies would have been clearer for this purpose.

I am not saying that frameworks or architectures are a bad approach. In fact I believe they are a good methodology. But, I think if you are going to develop a framework, you need to develop it in the joint arena. This is what I think led to the success of the DIS protocols for distributive applications and the failure of JMASS. JMASS was a good idea in my opinion, but it failed because it was developed too long in isolation from potential users. The result is that the investment made in JMASS far exceeded the value obtained by the joint community. While in some cases this may boil down to political issues over technical ones, they are

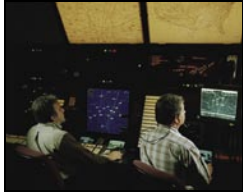
no less real obstacles to acceptance.

I also agree with you that the "one size fits all" approach will rarely be the best solution for the joint community. But with limited resources to apply to M&S, it behooves us to work with the broad user community to address unmet requirements in an efficient way. This still may entail multiple applications. This begs the question. What capabilities exist in the Endgame Framework that are not available in other current endgame tools? Who needs these capabilities?

In closing, it is not up to me what articles are published in Aircraft Survivability. However, I would oppose a follow-on article on this subject for two reasons. First the purpose of this journal is primarily to be a newsletter for the work of the Joint Survivability Community sponsored by the JASPO. Endgame Framework is not one of these projects. However, as indicated above, the JASPO sponsored JMUM is an available venue for you to let the community know of your tool. Second, space is very limited in this journal. For example, some JASPO related articles were dropped from the current issue due to space after they were written. Obviously, these articles should have preference to non-JASPO projects. I saw that CDR Chisholm did offer you a letter spot. This may be a more appropriate avenue. If you decide to go this route, I will respond as appropriate.

Respectfully,

Ron Ketcham
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National Aeronautics and Space Administration (NASA)

Aircraft Hardening and Airspace Security Research

■ by Mr. Douglas A. Rohn

In the preface to the National Strategy for Homeland Security, July 16, 2002, President George W. Bush stated, “The U.S. government has no more important mission than protecting the homeland from future terrorist attacks,” and that “We must rally our entire society to overcome a new and very complex challenge. Homeland security is a shared responsibility.” Part of the Federal government’s response to this challenge are new projects within the National Aeronautics and Space Administration’s (NASA) Aviation Safety and Security Program that seek to develop technologies to address certain security needs of the current and future national air-transportation system. Since its inception, NASA’s long-range research and development capabilities have provided advances in all areas of aviation; therefore, as noted by NASA Administrator Sean O’Keefe in the NASA 2003 Strategic Plan, “The increasingly complex and dangerous international arena compels us to aggressively apply our expertise and technologies to improve homeland security.”

Within its Aeronautics Research Mission area, NASA’s objectives are to protect air travelers, the public, the nation, and the environment; to increase mobility; and to explore new aeronautical missions. To meet these objectives, programs have been ongoing to develop technologies for new or advanced vehicle concepts, to reduce emissions and noise, to increase the national airspace-system capacity, and to minimize accidents. New projects that will provide technology to help reduce vulnerability to hostile acts, both directly to aircraft and throughout the air-transportation

system, are an extension of similar work being applied to the problems of safety, capacity, vehicle, emission, and system capacity. NASA is conducting this research in close collaboration with other agencies, including the U.S. Department of Defense (DoD), the Transportation Security Administration (TSA), the Department of Homeland Security (DHS), and the U.S. Federal Aviation Administration (FAA). This article will provide a summary of the activities currently under way within NASA’s Aviation Safety & Security Program (AvSSP).

Overview of the Aviation Safety and Security Program (AvSSP)

The objective of the AvSSP is to develop technology that enables a reduction in the commercial aviation accident rate, increases the robustness of the national air-transportation system to hostile acts, and identifies potential aviation-system vulnerabilities. Reductions in accidents can only be accomplished through a coordinated effort of the aviation community: developers, operators, regulators, users, *etc.* NASA’s approach for safety has been to work with all members of the community and apply its skills to eliminate targeted accident categories, strengthen the foundation of safety technology, increase accident survivability, and accelerate implementation of new technology by all users and to all vehicle classes. The projects that treat the “safety” portion of that objective have been under way since FY2000. As shown in Figure 1 (see page 19), these projects focus on developing technologies to be applied directly to the aircraft itself, technologies to be applied to solve weather-related problems, and safety enhancements

to be applied throughout the transportation system.

NASA’s approach for security is similar. By applying its skills and capabilities to specific problems and working with our partners, NASA seeks to identify and respond to threats and hostile acts, mitigate their effects, and qualify and transfer technologies for a robust system and infrastructure. NASA has focused on five general application areas: harden and protect the aircraft, secure vehicle Communication, Navigation, and Surveillance (CNS) systems, secure the national airspace system, increase effectiveness of information screening, and integrate advanced sensors into aircraft. As shown in Figure 2 (see page 20), there are three projects that are organized from these five foci.

Aircraft and Systems Vulnerability Mitigation Project

Since those with malicious intent will continually seek new ways to carry out attacks, dealing with the consequences of hostile acts is part of a balanced way to protect the traveling public and the commercial air-transportation system. The objective of the Aircraft and Systems Vulnerability Mitigation (A&SVM) Project is to develop and advance technologies that will mitigate consequences to an aircraft from an intentional attack. To address the potential threat of terrorists who continue to use commercial and general aviation aircraft as weapons of mass destruction, the government and national aviation community’s first priority is to prevent terrorists from boarding commercial aircraft or getting any type of weapon onboard. For this reason, the system now includes

increased baggage checks and the use of federalized screeners; improved passenger-screening programs are now under development. The second priority is to prevent terrorists from overpowering a crew and taking control of the aircraft if they do get on board. Measures in place now include Federal Flight Deck Officers, hardened cockpit doors, and additional Federal Air Marshals. If these interventions are unsuccessful, then it would be necessary to prevent hijackers from using the aircraft for other than its intended purposes. It is in this area, and on technology to mitigate other intentional damage scenarios, that A&SVM focuses its research efforts.

Protected Asset Flight System (PAFS) and Flight Evaluation for Aircraft Recovery (FEAR)

As shown in Figure 3 (see page 21), A&SVM is organized into seven sub-projects. The first two sub-projects, Protected Asset Flight System (PAFS) and Flight Evaluation for Aircraft Recovery (FEAR), are focused on reducing the likelihood that hijacked aircraft can be used as weapons while protecting both aircraft and occupants. The ability to accurately determine the real-time transfer of aircraft control from authorized crew members to terrorists and to identify aircraft controlled for hostile intentions does not currently exist. Likewise, the ability to take away control from a hostile pilot and land an aircraft safely remains a challenge for the future. The accurate identification of a threat to an aircraft is essential, and making this determination will require fusion of inputs from several different sources through well-considered decision-making algorithms.

The objectives of PAFS and FEAR are as follows—

1. Develop requirements and methods for establishing, using, and distributing aircraft threat-level information (“hostile” or “friendly”);
2. Develop and evaluate technologies for on-board methods to avoid incursions into protected airspace and intentional hostile acts;



Figure 1. NASA aviation safety projects

3. Address questions of the safe recovery of a hijacked aircraft and its passengers; and
4. Establish operational requirements, concepts, and processes necessary to integrate these technologies with the air crew, aircraft systems, and the air-space system.

Research will address methods to identify who is flying the plane and develop the ability to trigger a transition to a more secure mode of an on-board crash-avoidance system—potentially one that could not be overridden by the pilot—focused on the safe recovery of the aircraft and passengers. The PAFS concept of operation is shown in Figure 4 (see page 22). Candidate technology areas include biometric identification; video surveillance, storage, and transmission; proximity and direct-access control; acoustic monitoring and analysis; intent determination; airborne transponders; Radio Frequency Identification (RFI); integrated cockpit avionics and displays; collision-avoidance systems such as weather-avoidance systems and Traffic Alert/Collision Avoidance System (TCAS); collision-detection sensors; flight-management and control systems; flight-maneuver monitoring, analysis, and limitation; and airborne data link.

Electromagnetic Effects Surveillance and Detection (EME)

The goal of Electromagnetic Effects Surveillance and Detection (EME) is also to prevent an aircraft from being used as weapons or to prevent the destruction of an aircraft by protecting against accidental or deliberate flight-path deviations caused either wholly or in part by Radio Frequency (RF) attack. Even though aircraft systems are certified against the negative effects of High Intensity Radiated Fields, they may still be susceptible to RF attack. The effects of an RF attack on commercial aircraft are not readily apparent or as well understood as existing Electromagnetic (EM) modeling and simulation capabilities that are designed for nominal conditions. Furthermore, airports are also potentially susceptible to RF attack,

causing disruption, delays, and economic losses.

The approach taken by EME is to develop technology, procedures, and implementation methods for an integrated on-board EM surveillance system that interfaces with a vehicle's health-management system. Advanced modeling and simulation techniques will be developed and used to predict RF propagation inside aircraft cabins and airports and will be used to aid in developing requirements and technologies to protect aircraft radios and navigation equipment against intentional RF attack.

Damage Adaptive Control Systems (DACS)

The goal of Damage Adaptive Control Systems (DACS) is to mitigate in-flight safety and security risk of terrorist threats to an aircraft and the public by improving surviv-

ability from vehicle damage brought about by Man-Portable Air Defense Systems (MANPADS), longer-range Surface to Air Missile Systems (SAMS), on-board sabotage, anti-aircraft weapons, and other sources of malicious damage.

DACS provides an integrated approach to MANPADS damage modeling, safety of flight assessment, and damage mitigation. Damage-modeling requirements and data will be generated for aerodynamic properties, the engine, airframe, and vehicle components. Enhanced flight simulations and damage emulation will be developed using damage models and data. An assessment of MANPADS damage effects on aircraft safety-of-flight and recovery capabilities will be conducted. This assessment will address such factors as the capability and probability of vehicle recovery with sustainable



Figure 2. NASA aviation security projects



Protected Asset Flight Systems
Flight systems to deny use of aircraft as weapon or protected area intrusion

Flight Evaluation for Aircraft Recovery
Capability to safely recover a seized aircraft to landing



Damage Adaptive Control Systems
Aircraft safety of flight and controls system accommodations to mitigate effects of damage from shoulder-launched missiles



Electromagnetic Effects Surveillance and Detection
Develop technologies to further secure and harden on-board aircraft systems from intentional RF threats and enable EM surveillance of the aircraft environment



Fuel Protection
Fuel system technologies that prevent or minimize in-flight vulnerability to small arms, MANPADS, or other projectiles

Fire Resistant, High-Energy Damage Tolerant Composite Structures
Affordable, light weight, fire resistant, material & composite structures with unparalleled high-energy damage tolerance

damage given the vehicle configuration, effects of damage, technologies for adaptive control recovery and reconfiguration, and flight scenarios. Enhanced flight simulations with damage models will be utilized in this study.

Fuel Protection (FP)

The Fuel Protection (FP) sub-project is aimed at preventing fuel-tank explosion/fire in the event of MANPADS or small-arms attack. The lethality of these weapons against large aircraft depends to a great extent on the weapons' ability to use moderate impact and explosion effects to initiate a secondary explosion of an aircraft's fuel tanks, thereby magnifying the damage to a catastrophic level at which flight cannot be maintained.

FP seeks to enable adaptation of military-heritage fuel-tank inerting to commercial air-transport aircraft to provide adequate protection within the economic reach of commercial transport operations. To meet this objective, FP will develop and deliver technologies that will counter the very large cost penalty that commercial flight operators would incur for adding fuel-tank inerting to their aircraft, while still providing sufficient protection. Potential technologies include flammability feedback control and key components for advanced control of inerting systems and design guidelines to assist designers in performing timely design, sizing, and aircraft integration of inerting systems matched to commercial air-transport designs.

Fire Resistant, Damage Tolerant Composites (FRDTC)

The objective of Fire Resistant, Damage Tolerant Composites (FRDTC) research is to develop affordable, lightweight, fire-resistant, composite structures with unparalleled high-energy damage tolerance. If an explosion were to occur on an airplane regardless of its origin (explosion in the fuselage or cargo bay or as a result of a missile strike), damage would occur to the structure. This damage could result in the loss of the vehicle. Furthermore, carbon fibers (the principle reinforcement for

composites) are electrically conductive and can cause considerable damage to electrical equipment of all types (computers, communications, radar, guidance systems, *etc.*) when released into the atmosphere during a fire.

The use of exterior composite structures on commercial aircraft is increasing. NASA's advanced material and structural technology is being applied to mitigate the effects of damage caused by an explosion, which typically involves a high-pressure pulse loading followed by fragment penetration, by developing new composite structures with high-energy damage tolerance. These material and structures are envisioned to be available for next generation commercial and general aviation applications.

Secure Aircraft Systems for Information Flow Project (SASIF)

The objective of the Secure Aircraft Systems for Information Flow (SASIF) Project is to secure aircraft networks and communication links from intentional threats, enable surveillance of aircraft, and minimize protected airspace intrusions. The solutions being addressed by SASIF begin with "hardened" on-board aircraft systems but also go beyond into "hardening" the airspace system. With the rapid increase of datalink and information technologies in the aircraft and the National Airspace System, the vulnerabilities of cyber threats have also increased. SASIF technologies will help protect air travelers and ensure that CNS systems on aircraft cannot be compromised.

SASIF research is conducted in three specific areas: surveillance, communications, and datalink and network hardening. The surveillance objectives include enabling protected airspace surveillance-system concepts and technologies by looking at data fusion and other technologies. The datalink and network research is focused on detecting and protecting against network intrusion and hardening key network delivery systems including air-traffic control communications, aircraft data links, and on-board networks. Finally, the communications activities look at ways to remotely monitor on-board sys-

Figure 3. Aircraft and Systems Vulnerability Mitigation Project

tems and the aircraft environment for information sharing and decision making. This application-focused research focuses on emergency communications and securing on-board information downlinks and uplinks.

System Vulnerability Detection Project (SVD)

The identification of new and emerging vulnerabilities is important to decision makers who react to those threats and to researchers who will develop further prevention and mitigation technologies. Some of these occur beyond the realm of an aircraft itself; *i.e.*, within the airspace system and in airports. NASA's System Vulnerability Detection (SVD) Project leverages capabilities in several key areas in which vulnerabilities can be detected. Its objective is to advance technologies that detect and inform users of potential security vulnerabilities in the National Air Transportation System. The four sub-projects that make up SVD are shown in Figure 5 (see page 23).

Secure Airspace Decision Support Tool (SADST)

As the attacks on September 11 demonstrated, rapid detection and coordinated response to an aircraft that suddenly deviates from its flight path is now a critical component

of any modern air-traffic management system. The Secure Airspace Decision Support Tool (SADST) sub-project's focus is on developing tools that will enable an electronically coordinated, automation-assisted response to aircraft that are deviating from their planned flight paths. The current tool, known as the Rogue Evaluation and Coordination Tool (REACT), is being built on the suite of air-traffic control automation tools known as CTAS, the Center/Terminal Radar Approach Control (TRACON) Automation System. Several new graphical features and algorithms are being added to the CTAS baseline to enhance tracking and adaptation to special circumstances. The response capability will include conflict detection and resolution with other aircraft, prediction of intrusion into secure airspace and of likely ground targets, and coordinated decision support between multiple facilities and agencies.

Knowledge Discovery Tools for System-Wide Security (KDTWS)

The goal of NASA's Knowledge Discovery Tools for System-Wide Security (KDTWS) is to enable better real-time evaluation of threat scenarios in aviation by creating tools for threat assessment using

advanced data-mining and knowledge-discovery techniques for distributed heterogeneous data. Mining of data can be used to discover knowledge about threat patterns involving cargo and air traffic. The benefits include reducing costs for discovering potential vulnerabilities using data-mining techniques while at the same time reducing vulnerabilities to the entire air transportation system. Using existing NASA technology, the research will focus on developing tools to discover rules, relationships, and anomalies about security threats.

Security Incident Reporting System (SIRS)

Shortly after September 11, the Aviation Safety Reporting System (ASRS), funded by the FAA and operated by NASA, began receiving reports from pilots, flight attendants, and mechanics about aviation security events. The ASRS is a trusted, confidential, non-punitive reporting system, developed in 1976, to gather and use safety information from aviation stakeholders to identify vulnerabilities and alert decision makers to potential problems. Building on the success of ASRS, NASA will develop the Security Incident Reporting System (SIRS). Its objectives are to provide a national, confidential, non-punitive

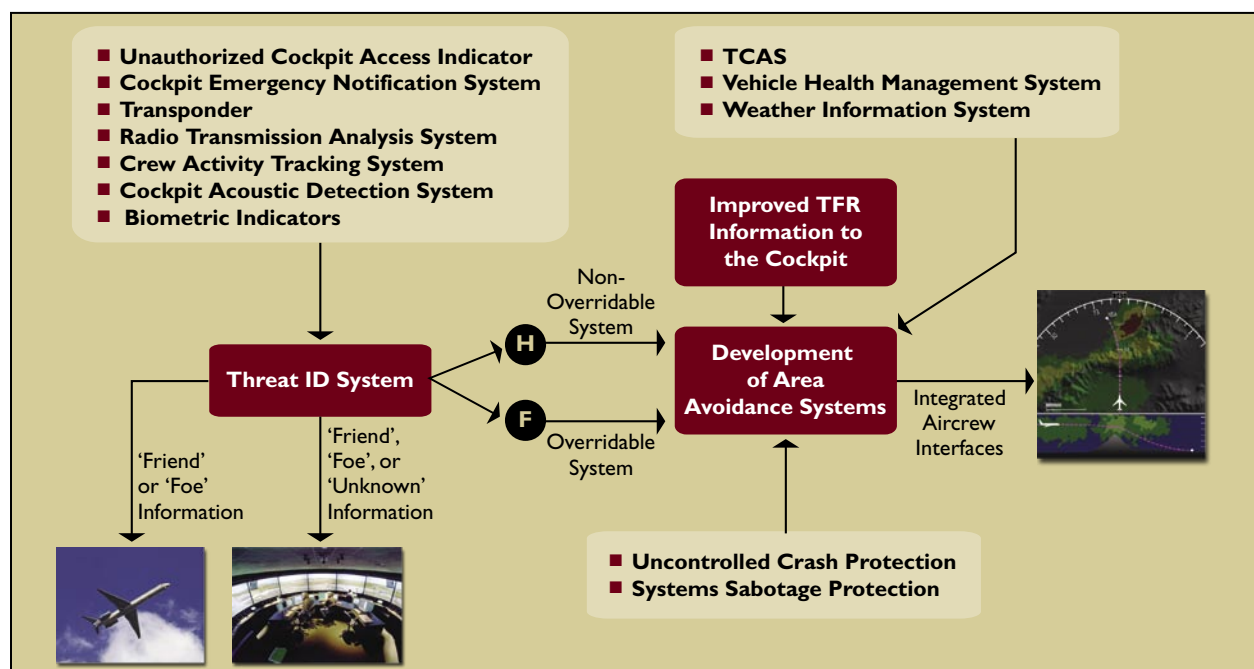


Figure 4. Protected asset flight system concept of operation



Figure 5. System Vulnerability Detection Project

reporting environment for aviation security issues; gather information on security-system events from TSA personnel, law enforcement, airport employees, airline employees, and other aviation system stakeholders; identify vulnerabilities that may not be discernable through other reporting avenues; and alert decision makers to potential problems for appropriate follow-up action.

The concept of SIRS is simple. Individuals voluntarily submit reports containing issues they believe to be security concerns or system problems. These security incident reports are analyzed by SIRS security experts, reviewed by NASA, and distributed appropriately to those authorities and organizations in a position to address potential deficiencies and discrepancies. Essential to its success is the confidence and trust in the reporting system by the person reporting. Key challenges are to educate new users, instill trust, provide immunity and incentives to reporters, and resolve legal issues concerning the protection and distribution of sensitive security information. To meet these challenges, partnering relationships have been established with TSA, FAA, airport police, FAMS, the Federal Bureau of Investigation (FBI), police associations, airport managers and

airport security managers, and aviation organizations such as the Airline Pilots Association (ALPA), AFA, IAM, the Aircraft Owners and Pilots Association (AOPA), ATA, and others.

Sensing of On-Board Chemical and Biological Contamination (SOCBC)

The objective of Sensors for On-Board Chemical & Biological Contamination (SOCBC) is to develop a chemical and a biological sensor and warning system for specific threats. The eventual goal is to develop and advance technologies that will mitigate the consequences from an intentional on-board release of toxic agents within an aircraft cabin. The research involves identifying the chemical/biological background in aircraft cabin air, providing requirements to technology developers, and validating prototype hardware sensor systems. Sensor development will leverage NASA's extensive investments in sensors and technologies ranging from safeguarding the environment for humans on board a space station, protecting planets with bacteria and spore detectors, and sterilizing exploration vehicles.

Summary

NASA research and development in aircraft and aviation system

security is focused on developing high-risk, long-range technologies. The work primarily involves vulnerability mitigation, but concepts for detection of new vulnerabilities are also included. Most technology products are leveraged from other NASA aeronautics research, using the unique skills and capabilities of NASA and partnered members of the aviation community, and many involve leveraging military technology for commercial application. ■

Mr. Douglas A. Rohn received his M.S. in Mechanical Engineering from The University of Toledo, and Bachelors of Mechanical Engineering from Cleveland State University. During his 26 years at the NASA Glenn Research Center, he has performed research in aerospace mechanical components, including traction drives, helicopter transmissions, spacecraft mechanisms and robotics. Recently, Mr. Rohn managed projects in Aerospace Propulsion and Aviation Safety. He currently is serving as the Acting Deputy for Aviation Security Research in NASA's Aviation Safety & Security Program. He may be reached douglas.a.rohn@nasa.gov.



The Transportation Security Administration's

Commercial Aircraft Hardening Program

■ by Mr. Howard J. Fleisher

In December 1988, 270 people lost their lives when Pan American Flight 103 exploded in flight over Lockerbie, Scotland, because an improvised explosive device, located in the cargo hold of the Boeing 747 aircraft, was detonated. The Federal Aviation Administration (FAA) initiated the Commercial Aircraft Hardening Program (CAHP) in 1990 in direct response to this event, the directives of the 1990 Presidential Commission on Aviation Security and Terrorism, and the mandates set forth in the Aviation Security Improvement Act of 1990 (Public Law 101-604). The program was reconfirmed by the 1997 White House Commission on Aviation Safety and Security and again in the Aviation Security and Transportation Act of 2001 (Public Law 107-71), which transferred program responsibility to the Transportation Security Administration (TSA).

The overriding historical goal of the program has been to protect commercial aircraft from catastrophic structural or critical-system failure caused by an in-flight explosion or other terrorist-initiated event. The program has been focused on determining and identifying the minimum size explosive that would result in aircraft loss. The data collected in this research is being used to validate and refine standards for explosives detection at checkpoints and in checked luggage and cargo. Methods and techniques are also being studied that can be applied to the current and future fleet of commercial aircraft to decrease the level of vulnerability to internal explosive effects. Finally, in addition to internal explosive threats,

the CAHP assesses other intentional threats to aircraft including electromagnetic interference, projected energy, Man-Portable Air Defense Systems (MANPADS), and small-arms fire. The program has been organized into distinct areas, including cargo-hold protection, passenger-cabin protection, and protection from MANPADS and standoff weapons.

More recently, the mission of the technology area has been expanded to include other modes of pub-

lic transportation, including rail and maritime.

Vulnerability Assessment

The survivability of a commercial aircraft is a function of two distinct elements: susceptibility and vulnerability. Susceptibility is the probability that explosives of a particular nature and amount are successfully placed on board an aircraft. For the passenger cabin, this probability is a function of the performance of screening systems and operators at checkpoints and of the possible

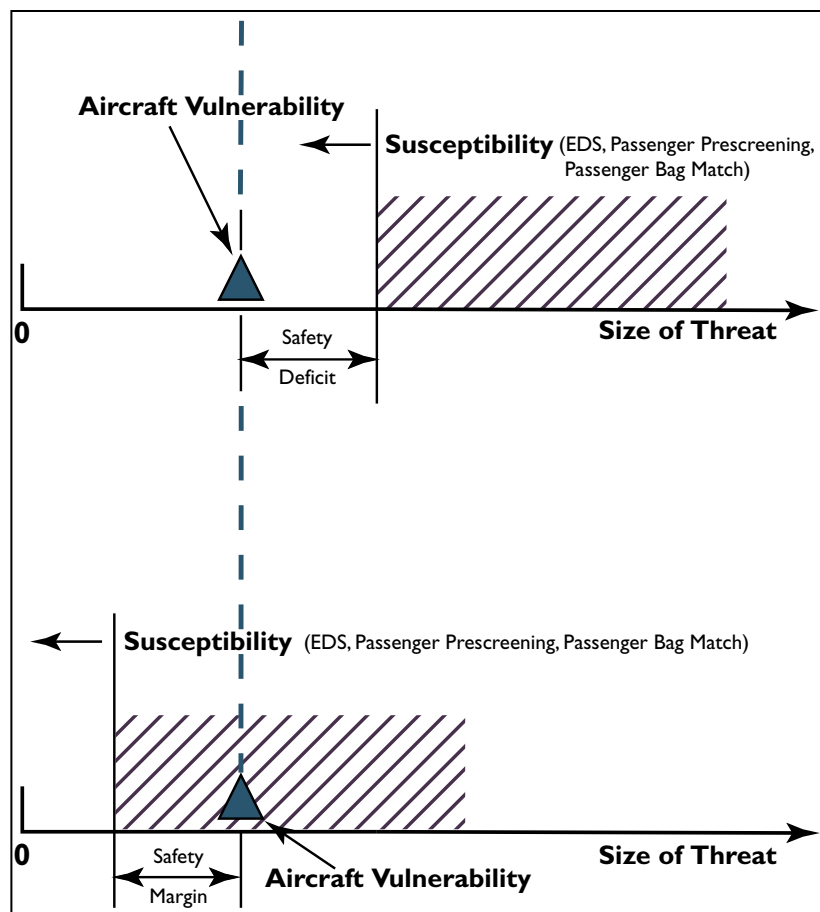


Figure 1. Susceptibility-vulnerability interrelationship

use of Computer Assisted Passenger Prescreening Systems (CAPPS). For the cargo hold, this probability is a function of the performance of checked-baggage Explosives Detection Systems (EDS) and EDS operators and of the possible use of CAPPS and positive passenger-baggage matching. Vulnerability is the conditional probability that an aircraft will be destroyed or suffer some specific level of damage if an explosion takes place on board. This probability is a function of the characteristics of the explosive charge (e.g., weight, type, location) and of the design capability of the aircraft structure to withstand the explosive forces and potential consequences. The interrelation between susceptibility and vulnerability is illustrated in Figure 1 (see page 24), in which the bottom graphic in the figure represents the desired end-state.

There are several hundred models of commercial aircraft in service today. Each model possesses its own set of dimensional, weight, power-plant, and performance metrics. These differences in design generally do not lend themselves to single solutions in terms of assessing survivability and developing mitigation technology. To enable sufficient and adequate use of resources, transport category

aircraft (those certified under Part 25 of FAA Regulations) have been the primary focus of the program's attention. There are three broad classes of aircraft, classified largely on the basis of fuselage diameter: wide-body (twin-aisle jet), narrow-body (single-aisle jet), and regional. The U.S. passenger fleet is dominated by the narrow-body jet, which represents approximately 59 percent of all aircraft, with wide-body jets, predominantly used in international flights, representing approximately 11 percent. Regional jets represent the remaining 30 percent. Passenger aircraft models of interest to the program are summarized in Table 1 (see below). In addition to the model type, the estimated passenger seating capacity is provided.

As the data in Table 1 (see below) show, there is a considerable variety in body class, airframe type, and specific model. Even aircraft within the same model family can vary significantly in terms of interior design, as this is typically customized to reflect the requests of the air carrier making the purchase. This great disparity in airframe characteristics provides a challenging environment in which to conduct broad survivability assessments and to develop widely applicable tech-

nologies to reduce susceptibility and vulnerability.

Working with aircraft manufacturers and the U.S. Department of Defense (DoD), the CAHP has researched the effects of internal blast on the current and future fleet of commercial aircraft. Since 1992, the program has conducted over 100 explosive tests on commercial aircraft structures, including a joint test on a Boeing 747 with the United Kingdom, a test with the Boeing Company on an L1011 aircraft, and tests on DC-9, DC-10, Boeing 727 and 737, and Airbus A300 airframes.

In addition to the full-scale airframe tests, supporting-data tests have been conducted that have permitted researchers to characterize the properties of luggage and luggage containers by explosive properties and expected fragmentation profiles. This information has been useful in developing analytical models and has provided a means to allow for interpolation and extrapolation of test results to other initial conditions. For example, Figure 2 (see page 26) illustrates the affect of luggage content on blast overpressures generated by the detonation of an Improvised Explosive Device (IED). Basic research into internal blast effects continues.

Table 1. Transport category aircraft models

Model	Seating	Model	Seating
Narrow-Body Jet Aircraft			
A-318	107	B-757-200/300	200-243
A-319/320/321	124-185	DC-9-40, 50	120-135
B-717	106	MD-80 series	117-143
B-727	94-145	MD-90	139-208
B-737 (200-900)	120-177		
Wide-Body Jet Aircraft			
A-300/310	220-280	B-747-200/300	366-496
A-330	253-440	B-747-400	266-568
A-340	239-475	B-767-200/300	181-218
DC-10/MD-11	181-380	B-767-400	245
L-1011	N/A	B-777-200	301-305
Regional Jet Aircraft			
BAE 146	70-112	DO-328	32-34
CRJ-100	50	EMB-135	37
CRJ-200	50	EMB-145	50
CRJ-700	70-75	EMB-170	70-78
CRJ-900	90	ERJ-145	50

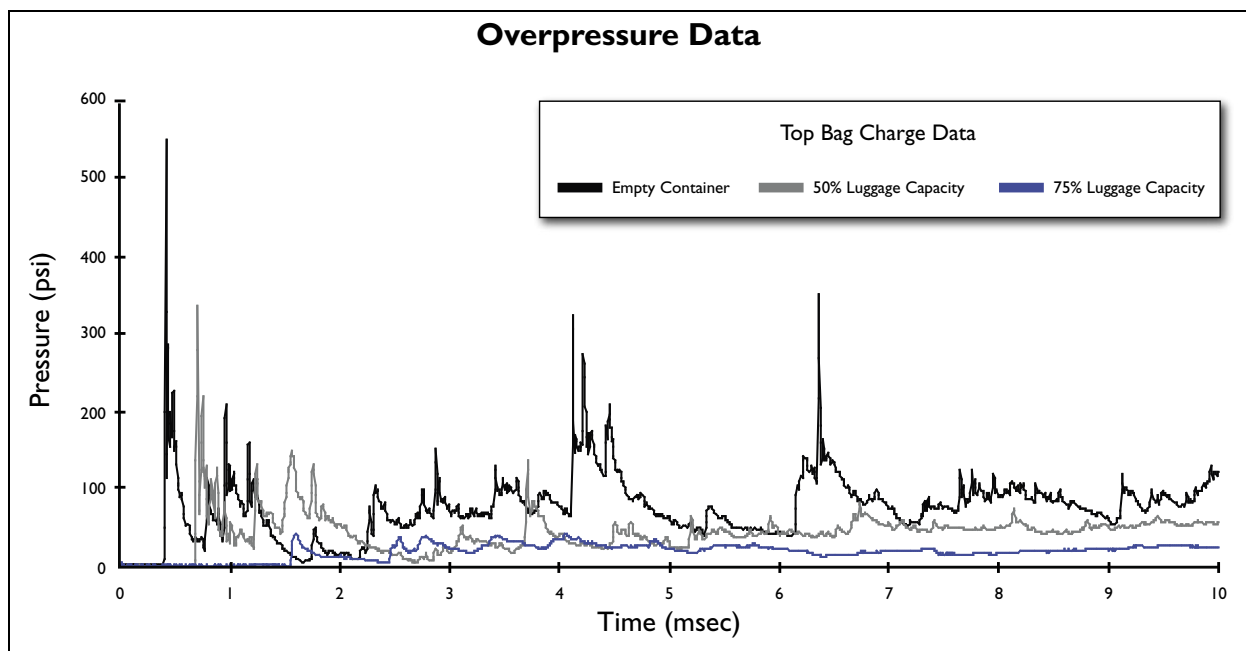


Figure 2. Overpressure chart

The data and assessments generated from the test program have allowed the CAHP to develop a family of aircraft-survivability curves, each dependent on aircraft class and threat type. These curves can then be used to determine if standards for explosives detection are appropriate and, if not, to what extent they may require revision.

Mitigation

Aircraft-vulnerability assessments and testing have provided sufficient data to enable the CAHP to identify, investigate, and develop measures that increase the survivability of commercial aircraft to internal explosive detonations. Concepts investigated include explosive-mitigation liners, hardened overhead stowage bins, and hardened containers, commonly known as Hardened Unit Load Devices (HULDs).

HULD research was initiated as a result of the Aviation Security Improvement Act of 1990. Initial efforts focused on determining the technical feasibility of incorporating blast-mitigating features into a pre-determined container geometry at a reasonable unit tare weight. This entailed the development of analytical models and full-scale explosive testing of both standard container designs and of prototype-hardened

containers. Once the feasibility was proven, performance specifications and protocols for design validation were developed.

To obtain security approval, a candidate blast-resistant container design is subjected to three different tests, including component testing to establish that fragmentation-resistance requirements are satisfied and shock holing to establish that materials are strong enough to withstand shock loads from an explosive detonation in close proximity to the material surface. Finally, a full-scale explosive-validation test is conducted in which the container is positioned within a wide-body aircraft cargo hold and loaded with an explosive device, which is then detonated. To pass this requirement, the container must maintain its integrity and cause minimal damage to the surrounding aircraft structure and systems.

The explosive threat that is required to be contained by the HULD exceeds the charge size specified in the Criteria for Certification of Explosives Detection Systems for a margin of safety. In addition to the security requirements, HULDs are also required to conform to existing airworthiness and airline operational requirements. Current focus has been

on the LD-3 classification of container, which is the most common type of passenger luggage container used on wide-bodied aircraft. The CAHP has conducted more than 50 explosive-validation tests of various HULD prototypes since 1992.

In 1998, a HULD designed by Galaxy Scientific Corporation became the first to satisfy the security requirements. In 2001, Telair International became the second manufacturer to pass the security-validation tests. A limited number of units from both manufacturers have been flown with airlines to obtain data on reliability and maintenance issues. HULDs were pulled out of service after various amounts of use to determine their residual blast capacity. The current goal of the hardened-container project is to assess the structural and func-



Figure 3. Typical aircraft explosive vulnerability test (DC-9, 2002)

tional readiness of HULD designs and to investigate both the operational and cost effectiveness of implementing hardened containers as a security measure. Unit tare weight, life-cycle cost, and maintainability remain the key issues. The program has initiated a process of design optimization with both HULD vendors to reduce container weight, acquisition, and life-cycle costs. These "2nd generation" designs should be available for testing in mid-2005.

Working with the Boeing company, the CAHP is also investigating the technical feasibility of enhancing the blast-resistance capacity of liners in the cargo holds and passenger cabins of passenger aircraft. This new initiative is intended to provide improved protection to the aircraft with a minimal impact on operational costs and will serve as a primary means of defense for those aircraft whose cargo holds are designed for non-containerized operations.

The Future

The CAHP continues its function as a test-centered activity with a

critical mission of transportation security. Vulnerability-assessment work permits the identification of measures and criteria for both the prevention (screening) and mitigation of threats. Recently, because of the expansion of the program's mission to other transportation modes, the program has been designated a key technology area and renamed Explosive Effects and Survivability.

As new threats to civil aviation and the U.S. transportation system evolve, the program will continue to determine their effects on commercial aircraft structure and systems and identify countermeasures, as appropriate. ■

Mr. Howard J. Fleisher is currently the Manager of the Protection Systems Research Development Test & Evaluation (RDT&E) Branch of the Transportation Security Laboratory, Transportation Security Administration, at the William J. Hughes Technical Center, New Jersey. Before assuming his current position, Mr. Fleisher managed the Commercial Aircraft Hardening Program from 2001–2003 and was Program Lead for Air Cargo Security

Research & Development (R&D) from 1998–2001. He has provided technical expertise in commercial aircraft vulnerability assessment, mitigation of explosive effects, and air-cargo security.

Before joining the Federal Government in 1997, Mr. Fleisher spent six years working for Galaxy Scientific Corporation, a company specializing in Aviation Technology R&D, where he was the Program Manager of the Structural Vulnerability Group. During his tenure at Galaxy, Mr. Fleisher led the project team that developed the first blast-resistant aircraft luggage container to successfully pass explosive validation testing.

Mr. Fleisher received a B.S. degree in Mechanical Engineering from the University of Pittsburgh, an M.S. degree in Mechanical and Aerospace Engineering from Rutgers University, and an M.B.A. from Rutgers University.

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Association for Unmanned Vehicle
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Joint Aircraft Survivability

Aircraft Survivability 2005 Air Vehicle Survivability Against New Global Threats 31 October -3 November Naval Postgraduate School, Monterey, California

**Explore Applications to Enhance Air Vehicle Survivability
Against the New Global Threats and the Analytical Techniques
and Test Resources to Support Their Development and
Evaluation**

Scope Includes: UAV, UCAV, Rotorcraft, Fighters, and Transports

Agenda Includes:

- Combat Reports, Lessons Learned, Threats, and Impact on Requirements
- Status of On-going Programs, Testing, ACTDs, and Experiments
- Promising Technology in Government, Industry, and Academic Labs

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CSI: On the Battlefield

■ by Ms. Melissa Winthrow

Air Force Research Laboratory Public Affairs (Tech. Sgt. Carl Norman, AFMC Public Affairs, contributed to this report).

Wright-Patterson Air Force Base, Ohio, (AFMCNS): Some of today's most popular television shows feature crime scene investigation, but those pale in comparison to the real-life battlefield investigations an Air Force Research Laboratory scientist carries out.

In his role in the Air Force Reserve, Maj. Greg Moster, whose civilian job is with AFRL's air vehicles directorate, is assigned to the Joint Combat Assessment Team—an elite 20-member group charged with delving into what type of explosive devices cause various vehicle battle damage.

Air Force organizations around the globe call on the team's unique abilities, according to Major Moster. And so do those from other services and branches of government, like the Department of Homeland Security for example.

"This type of work has been around since Vietnam, but has died out quite a bit in years past," he said. "It took on a whole new life when operations in Iraq started."

Major Moster said when the deployment call comes, he and his crew go to where the damaged vehicle is and start their examination. Damaged vehicles can be anything from jeeps and tanks to helicopters and other aircraft.

The first step, he said, is to review and access the actual damaged aircraft; then, collect weapon fragments and other evidence and send it for metallurgy analysis.

Those go to either the Missile and Space Intelligence Center in

Huntsville, Alabama, or the National Ground Intelligence Center in Virginia, depending on whether team members feel the suspect weapon is land or air based

"We also swab for chemical residue at the site and send it for analysis at a lab the Department of Homeland Security operates," he said. "That helps identify the type of explosives used."

Major Moster said he and his crew spend years studying the "finger prints" various types of missiles, grenades and so on leave—much like the television CSI teams look for certain pieces of evidence untrained eyes can't detect.

That personal identification, along with the metallurgy and forensics—like the chemical analysis—allows them to piece the puzzle together and identify what type of device damaged any particular vehicle.

"The physical damage looks different with each threat," Major Moster said. "I can pretty much tell you what class of device was used just by looking. It's the metallurgy and other forensics that confirm our suspicions."

In the past, the Joint Combat Assessment Team has investigated high profile cases such as Trans World Airlines Flight 800, which in July 1996 exploded shortly after takeoff from New York en route to Paris, as well as the F-117 Nighthawk lost in Kosovo in 1999.

In their latest assignment, Major Moster and two other team members spent six weeks deployed with the 3rd Marine Aviation Wing in Iraq. While enroute to meet with the Marines, team members also answered a request by the U.S. State Department and the Department of Homeland Security to help in the

on-going investigation of a DHL A300 aircraft hit by a missile over Baghdad in November 2003.

Throughout their deployment, the team, supported by the Missile and Space Intelligence Center and the Transportation Security Administration, used their crime scene investigation techniques and forensics to examine battle damage to the 3rd MAW's aircraft.

After determining what caused the damage, Major Moster and his colleagues then work with the impacted unit's intelligence officers and tacticians to coordinate tactics to counter the threat.

"For example, should they fly lower or higher?" he said. "If they fly lower, they may take more small arms fire, but if they fly higher, they're more prone to taking missile hits. We help them decide where they want to be and provide them more information so they can make that decision more rationally."

In addition to helping the Marines in this situation, Naval Air Systems Command experts used the teams' findings to determine the battle worthiness of certain Navy aircraft systems. Where possible, naval officials use the information to modify certain systems and make them more resistant to threats like the 3rd MAW unit encountered in Iraq.

The team's abilities and findings benefit everyone from the Air Force Materiel Command researcher to the people who control service funds, Major Moster said.

"Our investigations help determine how military units are engaging the enemy," he said. "We can see where the weaknesses are in a particular weapon system and that helps AFMC

do a better job in reducing the vulnerabilities in those particular areas.

“It can also help decrease the number of resources lost, help put more bombs on target and help Air Force leaders better determine where to put money so more lives can be saved.”

At AFRL, Major Moster is the leader for the Reusable Military Launch Systems Team, a joint effort between

the Air Force, National Aeronautics and Space Administration and contractors to design and evaluate access to space vehicles like the space shuttle.

Due to the classified nature of his Reserve job, the major, a real-life rocket scientist in his civilian job, cannot reveal many details about how many times he’s TDY and where he goes. However, he said he’s grateful for the support he

received from his civilian supervisors and co-workers because as a non-standard Individual Mobilization Augmentee, he serves much more than the traditional one weekend a month, two weeks per year commitment.

“The Air Force has been very understanding and very supportive,” he said. “I enjoy what I do very much and am glad it benefits others.” ■

continued from page 11

not treated the same in commercial and military designs. In commercial aircraft, cost saving can be made using single but very reliable components and routing aircraft systems to common “service centers” so that they can be easily accessed from a single location. Vulnerability reduction in combat aircraft suggests that redundancy and separation of redundant systems should be applied at the expense of reliability and ease of maintenance. The DC-10 hydraulic failure and 737 examples expose critical subsystems in these specific commercial aircraft that could be extremely vulnerable to single ballistic encounters. These subsystems would be prime candidates for redesign if these aircraft were to be used in military applications.

Conclusions

Commercial aircraft designs can provide huge cost benefits when applied to military program needs, but programs should consider that, in part, these savings result from reduced survivability. The programs must recognize and accept the costs necessary to get survivability back into the system. Two general aspects of vulnerability reduction need to be considered.

Some basic vulnerability reduction techniques can be effective for any large platforms and should be considered for every commercial platform used in a military application. Ullage inerting and dry-bay fire suppression significantly improve survivability as has been demonstrated in numerous live-fire test programs. These systems can be implemented as add-

ons to the basic aircraft and have little impact on the platform’s basic design. Programs should plan for the expenses of these systems and the design efforts necessary to ensure their effective implementation.

Programs need to understand the differences in philosophy in designing commercial versus combat aircraft and evaluate the design with these differences in mind. This may help to identify survivability weaknesses that might have otherwise been overlooked. This gives the program a chance to correct these deficiencies and make significant improvements in the aircraft’s overall effectiveness. ■

Dr. Torg Anderson is a member of the Operational Evaluation Division at the Institute for Defense Analyses in Alexandria, Virginia, where he supports aircraft live fire evaluations for several programs including the F-35, the Multi-mission Maritime Aircraft and the E-10A. He has 25 years of experience at United Technologies Research Center and Pratt & Whitney primarily working in aircraft engine combustor development and design and combustion diagnostics development. He is an active member of the AIAA Weapon Systems Effectiveness Technical Committee. He may be reached by E-mail at tanderso@ida.org.

Dr. Lenny Truett is a member of the Operational Evaluation Division at the Institute for Defense Analyses in Alexandria, Virginia, where he supports aircraft live fire evaluations for several programs including the C-5, C-17, C-130J, C-130 AMP and Airborne Laser. Before coming to IDA, he was a project engineer with the 46th Testing Wing at Wright-Patterson AFB specializing in fire and explosion suppression. He may be reached by E-mail at ltruett@ida.org.



Annual Survivability Awards Presented by Combat Survivability Division

■ by Mr. John Vice

The National Defense Industrial Association's (NDIA) Combat Survivability Awards for Lifetime Achievement, Leadership, and Technical Achievement were presented to Mr. Patrick S. Sharp, Mr. Richard A. (Tim) Horton, and Mr. Thomas L. Dobrenz, respectively, at the Aircraft Survivability 2004 Symposium held November 30 through December 2, 2004, at the Naval Postgraduate School (NPS), Monterey, California. These awards, presented annually at the NDIA Combat Survivability Division's Aircraft Survivability symposium, recognize individuals or teams who demonstrate superior performance across the entire spectrum of survivability, including susceptibility reduction, vulnerability reduction, and related modeling and simulation.

Combat Survivability Award for Leadership

The NDIA Combat Survivability Award for Leadership is presented to a person who has made major contributions to enhancing combat survivability. The individual selected must have demonstrated outstanding leadership in enhancing the overall discipline of combat survivability or have played a significant role in a major aspect of survivability design, program management, research and development, modeling and simulation, test and evaluation, education, or the development of standards. The emphasis of this award is on demonstrated superior leadership of a continuing nature.

Mr. Richard A. Horton, SURVICE Engineering Company, China Lake, California, received the 2004 Leadership Award. Mr. Horton was recognized for exceptional leadership

in the field of aircraft combat survivability. His operational experience, managerial expertise, and leadership, which span nearly 40 years, have enhanced the survivability of Navy and Marine Corps combat aircraft and have earned him the high regard and respect of the aircraft community. As the first Executive Director of the Joint Technical Coordinating Group on Aircraft Survivability (JTTCG/AS), Mr. Horton conceived and developed the concept of a full-service Information and Analysis Center for survivability information and was instrumental in establishing the Joint Live Fire (JLF) Program. Recently retired as head of four divisions at the Naval Air Warfare Center, China Lake, California, he has been responsible for improvements to survivability test facilities and has been a driving force behind survivability enhancements to all Navy and Marine Corps aircraft and weapons systems, including, most notably, the V-22 and F/A-18E/F programs. He has also served as the Navy Principal Member and Chairman of the Joint Aircraft Survivability Program Steering Group.

Combat Survivability Award for Technical Achievement

The NDIA Combat Survivability Award for Technical Achievement is presented to a person or team who has made a significant technical contribution to any aspect of survivability. It may be presented for a specific act or contribution or for exceptional technical performance over an extended period. Individuals at any level of experience are eligible for this award.

Mr. Thomas L. Dobrenz, Northrop Grumman Corporation, El Segundo, California, received the 2004 Technical Achievement award. Mr. Dobrenz was recognized for exceptional technical achievement in the

field of aircraft combat survivability. Throughout his 23-year career as an engineer and technical manager, he was instrumental in developing, fielding, and supporting a wide variety of highly survivable military aircraft. These have included the B-2, F/A-18, F-35, Joint STARS, F-14, E-2C, and EA-6B programs and the Tacit Blue experimental stealth platform. As the leader of the Survivability Integrated Product Team (IPT) for the Lockheed Martin Joint Strike Fighter Team, Mr. Dobrenz established the program plan for all survivability analysis and demonstration activities within the team, which included several technical breakthroughs in supportable low observables. As the leader of the Northrop Grumman Integrated Systems Sector Survivability and System Effectiveness, Mr. Dobrenz is responsible for all of Northrop Grumman's advanced research and development projects related to survivability, including a rapidly expanding portfolio of unmanned systems products. In this role, he made direct, positive contributions to Operation Enduring Freedom and Operation Iraqi Freedom.

Combat Survivability Lifetime Achievement Award

Unlike the annual Leadership and Technical Achievement Awards, the NDIA Combat Survivability Award for Lifetime Achievement is presented only when merited by the lifetime contributions of a noteworthy individual to the long-term enhancement of aircraft survivability and national security. Such a worthy individual was recognized at the 2004 Aircraft Survivability Symposium: Mr. Patrick S. Sharp of Modern Technology Solutions, Inc., Las Vegas, Nevada. Mr. Sharp was recognized for exceptional contributions to aircraft com-

bat survivability throughout a distinguished career in government and industry. During a lifetime of service to the U.S. Air Force in senior executive positions, Mr. Sharp played a key leadership role in developing and testing low observable aircraft, unmanned aerial vehicles, and advanced weapons. During assignments at the Air Force Flight Test Center and later as Technical Director to the Director of Special Programs, Assistant Secretary of the Air Force (Acquisition), he provided technical guidance and acquisition oversight for the Air Force, thereby ensuring the successful fielding of systems such as the F-117, B-1, Advanced Cruise Missile, B-2, F-22, Joint Air-to-Surface Standoff Missile, and numerous other classified programs. Mr. Sharp is clearly recognized as this country's leading expert in advanced air-vehicle signature-measurement technology and associated test techniques and in the synergy available through the proper combination of signature-reduction technologies and advanced electronic-warfare techniques. Mr. Sharp continues to serve the U.S. Department of Defense (DoD) and the defense industry as an influential member on a number of independent advisory boards and review groups. Mr. Sharp has also served as a mentor and advisor to many within our current aircraft survivability community. Several of our current DoD and industry leaders have benefited directly from his personal leadership and advice.

Best Poster Paper Awards

Three awards were presented for the best poster papers displayed as part of the symposium's Exhibits and Poster Papers feature. The first-place award was presented to Mr. James G. Cline, Lockheed Martin Aeronautics Company, Fort Worth, Texas, for his paper, "F/A-22 IR Signature Flight Test Model Validation;" the second-place award was presented to Mr. Charles E. Frankenburger, Naval Air Warfare Center-Weapons Division, China Lake, California, for his paper, "Survivable Engine Control Algorithm Development;" and the third-place was presented to Mr. Kevin Crosthwaite, Booz Allen Hamilton/SURVIAC, Dayton, Ohio, for his paper, "UAV Survivability Workshop Results." ■



From left to right: Roland P. Marquis, Chairman, Awards Committee, Combat Survivability Division; Mr. Richard A. (Tim) Horton and RADM Robert H. Gormley, USN (Ret), Chairman, NDIA Combat Survivability Division



From left to right: Roland P. Marquis, Chairman, Awards Committee, Combat Survivability Division; Mr. Patrick S. Sharp and RADM Robert H. Gormley, USN (Ret), Chairman, NDIA Combat Survivability Division



From left to right: Roland P. Marquis, Chairman, Awards Committee, Combat Survivability Division; Mr. Thomas Dobrenz and RADM Robert H. Gormley, USN (Ret), Chairman, NDIA Combat Survivability Division

Calendar of Events

APR

4–8, WPAFB, OH

Survivability Analysis Workshop
jeng_paul@bah.com

18–21, Austin, TX

46th AIAA/ASME/ASCE/AHS/
ASX Structures, Structural
Dynamic Materials Conference
www.aiaa.org/calendar

19–21, Wakefield, MA

Aircraft Fire and Explosion due
to Accidents, Combat and
Terrorist Attacks
www.blazetech.com/course_listings/course_listings.html

25–28, Eglin AFB, FL

2005 Meeting of the Military
Sensing Symposium (MSS) Specialty
Infrared Countermeasures
www.iriacenter.org

MAY

8–11, Orlando, FL

AAAA Annual Convention
“Transforming to Meet the
Warfighters Needs”
203.268.2450

10–11, Chantilly, VA

5th NRO/AIAA Space Launch
Integration Forum
www.aiaa.org

16–19, Atlantic City, NJ

5th NRO/AIAA Space Launch
Integration Forum
www.aiaa.org

JUN

1–2, Villanova, PA

Intelligent Ships VI Symposium 2005
www.navalengineers.org

6–8, Ontario, Canada

35th AIAA Fluid Dynamics, 4th
AIAA Theoretical Fluid Mechanics,
36th AIAA Plasmadynamics and
Lasers, 38th AIAA Thermophysics,
17th AIAA Computational Fluid
Dynamics, 23rd AIAA Applied
Aerodynamics Conference
www.aiaa.org

14–17, Colorado Springs, CO

JMUM
jeng_paul@bah.com

Information for inclusion in the
Calendar of Events may be sent to:

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